RADIOGRAPHIC IMAGE RECORDING TECHNIQUES WHEN USING COMPUTED RADIOGRAPHY IMAGING SYSTEMS IN THE EASTERN CAPE PROVINCE

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DECLARATION OF INDEPENDENT WORK

DECLARATION WITH REGARD TO INDEPENDENT WORK

I, CHARNÉ NEL, passport number and student number , do hereby declare that this research project submitted to the Central University of Technology Free State for the Degree MAGISTER TECHNOLOGIAE: HEALTH AND ENVIRONMENTAL SCIENCES, is my own independent work and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State and has not previously been submitted to any institution by myself or any other person in fulfilment of the requirements for the attainment of any qualification.

07/12/2018

SIGNATURE OF STUDENT	**DATE**

DEDICATION

This dissertation is dedicated to my late grandfather Zeeger de Jong. No amount of words are sufficient to express my gratitude for having you as a leader and role model. Thank you for your continuous influence on my courage and determination ability; rewarding my life and academic path with great optimism. Your motivational inspiration is absolutely immeasurable: “No matter what you choose to do in this life, do it to the best of your ability and never give up”. I live with you in my memory, always.

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ABSTRACT

Introduction

Computed Radiography (CR) is currently the main leading digital radiography system that was introduced to interchange from conventional film-screen radiography systems. The key advantage of CR over film-screen radiography is the ability to perform post-processing, which allows image recording faults to be rectified. This, inevitably leads one to inquire whether or not the required radiographic techniques are still being employed prior to post-processing when CR systems are used.

Aim of the study

The aim of this study was to assess and possibly enhance image recording techniques employed when using computed radiography imaging systems in private and government hospitals in the Eastern Cape province, South Africa.

Methodology

A retrospective study design, using a self-designed checklist, was utilised to assess the image recording techniques used by diagnostic radiographers when producing CR images. The checklist consists of quantitative data with qualitative elements. Images of the chest and abdomen were evaluated by the researcher and two other assessors. The team assessed a total of 720 (PA/AP and LAT) chest and (erect and supine) abdominal images individually, which were copied from the CR workstations for each assessor.

The data were categorically captured by the researcher and analysed by the quality assurance (QA) radiographer to ensure accuracy before sending the hard and soft copies of the sample to the statistician. Thus, the data were also provided to the statistician to verify the accuracy of the checklist results copied into an Excel spreadsheet, through the use of a data theme analyses technique. The technique that was used in the analysis was that of key-words-in-context. Descriptive data, namely frequencies and percentages, were calculated for categorical data. Means and standard deviations or medians and percentiles were calculated from the numerical data obtained.

Results

Image recording techniques assessed with a consistently high level of accuracy were ‘part selection on CR workstations’, ‘gridline artefact’ exclusion and ‘CR scanner malfunction’, which resulted in averages exceeding 95%. The results also indicated that an unacceptably high number of chest and abdominal examinations that were assessed had averages of non-optimal positioning: [chest (41%) and (abdomen 41%)], non-anatomical markers: [chest (73%) and abdomen (59%)], and no collimation applied: [chest (64%) and abdomen (72%)]. The most noticeable assessments relating to artefacts were foreign objects on the patients manifesting in PA/AP chest (14%), LAT chest (20%), erect abdominal (23%) and supine abdomen (13%) images.

Radiographers measure their processed images through EI values, which were assessed as either ‘over exposed’, ‘under exposed’ or ‘in range’. The EI results indicated that the majority of PA/AP chest was ‘in range’ (43%), whereas LAT chest was ‘under exposed’ (45%). Conversely, the abdominal images only showed underexposure as an average of 15% (18% for erect and 11% for supine abdominal images). It is striking to note that overexposure occurred in 52% of the abdominal images compared to 15% overexposure in chest images. Observed with assessment, histogram errors occurred in 7% LAT chest to 5% PA/AP chest, whereas erect and supine abdominal images had equivalent average histogram errors of 3% (n=16) each. Looking at the image quality assessment of all chest and abdominal images, satisfactory results relating to distortion, noise level and the degree of sharpness occurred. However, the study did identify that contrast and density technique image quality falling below an acceptable ‘3’ qualifier value could be improved in both chest and abdominal images assessed.

Conclusion and recommendations

All research questions and objectives of the study were addressed. This enabled the researcher to conclude that the three key areas requiring attention were: (i) radiographic practice, (ii) setting the exposure and (iii) avoiding artefacts through practical techniques. Recommendations are made to address these findings. Four sections, namely functional, technical, practical, and quality assurance recommendations are proposed.

Key words

Computed Radiography, Digital Radiography, Film-screen Radiography, Image Recording Techniques, Exposure Index (EI), Collimation, Anatomical Markers, Contrast, Density, Histograms

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ABBREVIATIONS

A

AGFA	Agfa-Gevaert N.V.
AOI	Area of interest
AP	Anterior Posterior
AXR	Abdominal X-ray

C

CEO	Chief executive officer
CNR	Contrast-to-noise ratio
CR	Computed radiography
CT	Computerised tomography
CUT	Central University of Technology
CXR	Chest X-ray

D

DICOM	Digital imaging and communications in medicine
DR	Digital radiography

E

EC	Eastern Cape
Ec	Ethics committee
EI	Exposure index

H

HPCSA	Health Professions Council of South Africa

I

ICCU	Intensive and critical care unit
IP	Image plate

L

LAT	Lateral

M

MRI	Magnetic resonance imaging

N

NX	Nautica Expo

P

PA	Posterior Anterior
PACS	Picture archiving and communication system

R

RIS	Radiology information system
RO	Research objective
RQ	Research question

S

SAS	Statistical analysis system
SNR	Signal-to-noise ratio

U

UFS	University of the Free State
US	Ultrasound

W

WSU	Walter Sisulu University

GLOSSARY OF TERMS

Agfa-Gevaert N.V. (AGFA)
The Agfa-Gevaert Group develops, manufactures and distributes an extensive range of analog and digital imaging systems and IT solutions, mainly for the printing industry and the healthcare sector, as well as for specific industrial applications (Agfa-Gevaert Group, 2017: online).

Artefact
An artefact is a feature in an image that masks or mimics a clinical feature (Willis, Thompson & Shepard, 2004: 11).

Brightness
Brightness is defined as the intensity of light that represents the individual pixels in the image on the monitor. In digital imaging, the term *brightness* replaces the film-based term *density* (Bontrager & Lampignano, 2014: 48).

Collimation
Restricting the primary x-ray beam by collimation not only reduces patient dose by reducing the volume of tissue irradiated but also improves image quality by reducing scatter radiation (Bontrager & Lampignano, 2014: 79).

Computed radiography
Consists of an imaging plate, which houses the photostimulable phosphor, is placed in a light-tight enclosure, exposed to the X-ray image and then read out by raster scanning with a laser to release the photostimulated luminescence signal (Nyathi, 2012:28).

Contrast
The density difference on adjacent areas of a radiographic image (Bontrager & Lampignano, 2014: 57).

Density
Radiographic film density is defined as the amount of "blackness" on the processed radiograph. When a radiograph with high density is viewed, less light is transmitted through the image (Bontrager & Lampignano, 2014: 37).

Digital radiography
The imaging system may be cassette-based or cassetteless. DR may use a flat panel with thin-film transistor or a charge-coupled device. The image reading process occurs immediately after the termination of the exposure and does not require the radiographer to initiate the reading process (ASRT, 2012: 25).

Distortion

It is the misrepresentation of an object size or shape, as projected onto radiographic recording media (Bontrager & Lampignano, 2014: 57).

Ethics committee

Ethics committee of the Faculty of Health Sciences of the University of the Free State.

Exposure creep

Exposure creep is the gradual increase in x-ray exposures over time that results in an increased radiation dose to the patient. It has been theorised as being a phenomenon that results from the wide-exposure latitude of computed radiography and direct/indirect digital radiography (Gibson & Davidson, 2011: 458).

Exposure index

The indicator is a vendor-specific value that provides the radiographer with an indication of the accuracy of their exposure settings for a specific image (Seibert & Morin, 2011: 573).

Grid

A grid is a device used to reduce the amount of scatter radiation reaching an x-ray film. Grids consist of parallel strips of radiopaque materials alternation with strips of radiolucent materials (Bontrager & Lampignano, 2014: 40).

Image plate

Light is trapped by the phosphor crystals (phosphorescence) after stimulation of x-rays. The crystals are called storage phosphors or imaging plates (Bushberg, 2002: 293).

Noise

Random disturbance that obscures or reduces clarity. In a radiographic image, this translates into a grainy or mottled appearance of the image (Bontrager & Lampignano, 2014: 57).

Radiographer

Allied health professional responsible for medical imaging, which is the taking of radiographs/medical images of the human body by using complex equipment (Medical Dictionary, 2018: online).

Source-to-image distance (SID)

The distance of the x-ray source from the IR (Bontrager & Lampignano, 2014: 37).

Unsharpness

A quantitative measure of the loss of edge detail due to geometric properties of the object and imaging system and not to image noise or X-ray scatter (Medical Dictionary, 2018: online).

CHAPTER 1

ORIENTATION TO THE STUDY

1.1 INTRODUCTION

During the 1980s, digital radiography imaging systems were introduced into medical imaging and rapidly replaced conventional film-screen radiography systems. Digital systems can be divided into two types: computed radiography (CR) and digital radiography (DR) (Carlton & Adler, 2013:324). CR is often the first digital radiographic system installed in a hospital because it can directly replace film-screen cassettes in existing radiography units (Bushberg, Seibert, Leidholdt & Boone, 2012: 226). DR, on the other hand, is a cassetteless system, therefore hospitals installing this system need to be retrofitted with the device if a new DR room is installed (Carter & Vealé, 2010: 7). Digitisation of imaging and the concurrent advances in network capabilities have led to the development of picture archiving and communication systems (PACS) and teleradiology networks.

The one key distinguishing advantage of CR systems over conventional film-screen radiography is that it allows for post-processing after an exposure has been made. Post-processing comprises, amongst others, image manipulation, annotation, collimation, density and contrast alteration to enhance or even rectify an imperfect radiographic image. These benefits are possible due to CR systems' broad exposure latitude and post-processing techniques (Körner, *et al*., 2007: 680). Using conventional film-screen radiography, alternatively requires precision in every aspect of image creation since the image is permanent and cannot be rectified or enhanced in any way after processing. As such, diagnostic radiographers must use optimal exposure factors, collimation and diagnostic markers, which must be placed anatomically correct. A question which comes to mind is: "Are the required radiographic techniques still being used prior to post-processing when using CR systems?"

The current study retrospectively assessed the image recording techniques of chest [posterioranterior/anteriorposterior (PA/AP) and lateral (LAT)] and abdominal (erect and supine) images processed, using CR systems in the radiology departments of two hospitals. The images were assessed prior to being manipulated in post-processing. Assessment was done in order to identify the changes that occurred after the exposed images had been processed. The assessment indicated which techniques required attention to produce an optimal CR image before post-processing.

The aim of this first chapter is to introduce the reader to the study by providing the background and context to the research problem. This introduction clarifies the overall research design and methods.

1.2 BACKGROUND TO THE RESEARCH PROBLEM

There are similarities and differences in the techniques used in CR and film-screen radiography imaging. As explained by Bushberg *et al.* (2012: 210), film-screen radiography images are created using a sheet of film with a light-sensitive emulsion on both sides that is sandwiched between two intensifying screens. CR imaging, on the other hand, uses a photostimulable, storage phosphor imaging plate (IP), which is situated in the cassette. No film is therefore required to create the image (Carlton & Adler, 2013: 339). Rather than emitting light when x-rays interact with it, the IP stores the x-ray energy in proportion to the intensity it receives (Carter & Vealé, 2010: 64).

Film-screen radiography is dependent on accurate exposure to achieve a faultless radiographic image prior to completion of the processing section. Unlike CR, there is no post-processing capability of changing exposure latitude. Thus, when a film-screen radiograph emerges from the film processor, the image is permanent and cannot be changed. It is therefore important that all technique factors associated with the production of the image are adjusted to produce optimum image quality; this includes viewing box illumination.

With CR, the reader scans the plate, light is released and an electronic signal is created and digitised. Within an exposure field, it is important for the CR scanner to distinguish the useful region of the image by locating the edges of collimation, referred to as 'collimation detection'. The default method for determining the useful signal for most CR scanners requires the construction of a grey-scale histogram, which is a graph with signal value (different brightness/pixel values) on the x-axis and relative occurrence on the y-axis (Siegel & Kolodner, 1999: 146).

Carlton and Adler (2013:350) list the histogram errors that could occur with the use of CR:

- focus and scatter;
- no collimation or too much collimation used;
- area of increased or decreased attenuation located in the body, where it is not normally located;
- multiple exposure on one plate and
- obtaining cross-table images.

The possible errors listed above are influenced by image recording techniques in CR. Incorrect techniques can cause inappropriate density and contrast of images, which will appear after post-processing (Carlton & Adler, 2013:350).

CR has both advantages and disadvantages and can therefore be considered as a 'double-edged sword' (cf. 2.5). The 'double-edged sword' relates to the considerable advantages to be gained from the proper use of CR which can however, be countered by potential disadvantages from its incorrect usage. An advantage of CR is its broad exposure latitude, which prevents unnecessary radiation exposures for replication purposes. Avoidance of replication images therefore also reduces radiation dose.

However, extremes of high exposure within the broad exposure range can increase the dose to patients. Extremes of low exposures create quantum mottle that can also lead to unnecessary radiation due to image replication. In other words, a decrease in quality and an increase in radiation dose may occur when CR is inappropriately used. This quantum mottle appearance also shows artefacts, which can be mistaken for pathology (Davidson, 2006: 62). For the reasons stated above, it is important to investigate whether or not CR image recording techniques are being correctly applied in radiology departments.

1.3 PROBLEM STATEMENT AND RESEARCH QUESTIONS

During an interview in a radiology department of a government hospital in the Eastern Cape province of South Africa, a member of staff raised an important concern. The member of staff Dr L. Balfour (2014), who is also an interventional Honours radiology student, indicated that post-processing, rather than appropriate radiographic image recording techniques, was being used to produce acceptable diagnostic radiographs in the department. Moreover, the researcher herself observed those important imaging techniques, such as the use of anatomical markers, collimation and an appropriate exposure technique, were being neglected during the examination of chest (PA/AP and LAT) and abdominal (erect and supine) images.

A distinguishing objective of a United Kingdom based research study done by CM Hayre is to inductively explore radiographic practices within the direct digital radiography environment supporting the National Health Service's continuous focus to "work at the limit of science – bringing the highest level of human knowledge and skills to save lives and improve health." An important distinction between Hayre's (2016:195) study and the methods applied in this study is that, where this study relied on the assessment of recorded images, Hayre's study gathered information through the observation of contemporary radiographic practices as well as conducting interviews with radiographers. Hayre's (2016: 197) study concluded that some radiographers acknowledged their lack of exposure manipulation prior to irradiating patients, thus relying on the "pre-set" exposures. Furthermore, it concluded that radiographers observed during this study were "whacking", "cranking" and "bumping up" exposures in order to ensure that they achieved images of diagnostic quality. (Hayre, 2016: 197).

One of the aims of a South African based research study done by Campbell (2017: 7), is to answer the research question: "What are the experiences of analogue-trained radiographers when utilising digital imaging for projection radiography?" An important distinction between Campbell's study and the aim of this study, is the fact that the researcher focused on ensuring that optimal radiographic image recording techniques are being used, whereas Campbell's study focused on the experiences of radiographers. Campbell's study concluded that radiographers were indifferent towards exposure selection, dose optimisation and placement of anatomical side markers (Campbell, 2017: 100).

Consequently, it can be stated that, due to advances in technology, the radiographic techniques of diagnostic radiographers should be reviewed to ensure that diagnostic images are optimally produced.

The main research question of the study can therefore be formulated as follows: How can the Eastern Cape Province hospitals, where computed radiography is used, ensure that optimal image recording techniques are being followed?

Three research questions are subsequently derived from the main research question:

RQ_1: Which CR image recording techniques are used at the private and government hospitals in the Eastern Cape Province?

RQ_2: Which radiographic image recording techniques have a potentially non-optimal influence on exposure index (EI) values?

RQ_3: Which radiographic pre-processing techniques (e.g. positioning, collimation, exposure techniques etc.) need to be optimised during examinations performed using CR in order to ensure optimal diagnostic images?

1.4 OVERALL GOAL, AIM AND OBJECTIVES OF THE STUDY

In the following section, the overall goal, aim and objectives of the study are outlined.

1.4.1 Overall goal of the study

The overall goal of the study is to examine CR image quality prior to post-processing and ensure that optimal radiographic image recording techniques are followed when using CR image acquisition systems. In order to achieve this goal, an assessment was undertaken of the current CR image recording techniques at the private and government hospitals.

1.4.2 Aim of the study

The aim of this study was to assess and possibly enhance image recording techniques employed when using computed radiography imaging systems in private and government hospitals in the Eastern Cape province.

1.4.3 Objectives of the study

To achieve the aim of the study, the following research objectives (RO) were formulated to address the aim of this study:

RO_1: To identify the CR image recording techniques used at private and government hospital in the Eastern Cape province.
This objective addresses research question 1.

RO_2: To identify the radiographic image recording techniques used that have a non-optimal influence on EI values.
This objective addresses research question 2.

RO_3: To develop recommendations to inform guidelines for optimising diagnostic images.
This objective addresses research question 3.

1.5 SCOPE OF THE STUDY

This study focused on the CR image recording techniques used in the Eastern Cape province radiology departments. The research explored the image recording techniques that were being used in modern CR image acquisition systems prior to post-processing, compared to conventional film-screen radiography image recording techniques. The scope included images recorded by diagnostic radiographers registered with the Health Professions Council of South Africa (HPCSA), in private and government hospitals in the Eastern Cape province of South Africa.

1.5.1 The researcher

The researcher involved in this study is a radiographer with a *Baccalaureus Technologiae* degree in Diagnostic Radiography and is registered with the HPCSA. She is currently working as a diagnostic radiographer at a government radiology department in the Eastern Cape province of South Africa.

Throughout her years of radiographic experience, the researcher has progressed from using conventional radiography systems to the more technologically advanced digital systems, such as CR. Based on her experience and observations, the researcher sought to discover whether the lack of proper image recording techniques was producing sub-optimal images and whether this could be rectified through recommendations.

1.6 SIGNIFICANCE AND VALUE OF THE STUDY

The study explored whether optimal image recording techniques were followed when using CR imaging prior to post-processing. The results of the study will possibly benefit all institutions using CR systems, as the recommendations can be used in other radiology departments. The study findings can also be shared further afield through publications or conferences. Furthermore, the recommendations can be used to develop a comprehensive guideline to ensure best practice. Since the core of the radiology profession is service delivery and patient care, the findings will enhance the profession by improving service delivery and patient care.

1.7 RESEARCH DESIGN AND METHODS

This section outlines a summary of the research design and methodology. Full details are available in Chapter 3.

1.7.1 Research design

A retrospective study design, using a self-designed checklist, was used to assess the image recording techniques followed by diagnostic radiographers when producing images. The research methodology consisted of quantitative data with qualitative elements. The data were obtained from the results of the assessed checklist and from recorded images stored by the researcher during the study. The recorded images were evaluated by the researcher and two assessors, therefore three assessors in total.

1.7.2 Methods of the research and flow of the study

The study assessed the image recording techniques used in chest (PA/AP and LAT) and abdominal (erect and supine) images in the radiology departments of two hospitals, prior to manipulation, after processing was done by the CR systems. Permission and ethical approval to conduct the study was obtained prior to the commencement of the study. The names of the hospitals involved in the research have been withheld to ensure the anonymity of the diagnostic radiographers. The method used in this study involved the researcher collecting data from where it were captured and stored at each hospital. The reason for this was to enable the three assessors to assess the data with the help of a checklist research tool. The checklist contained quantitative and qualitative components to address the objectives.

The outline of the research activities, data collection and analysis are presented in the schematic overview of the study in Figure 1.1 on the following page.

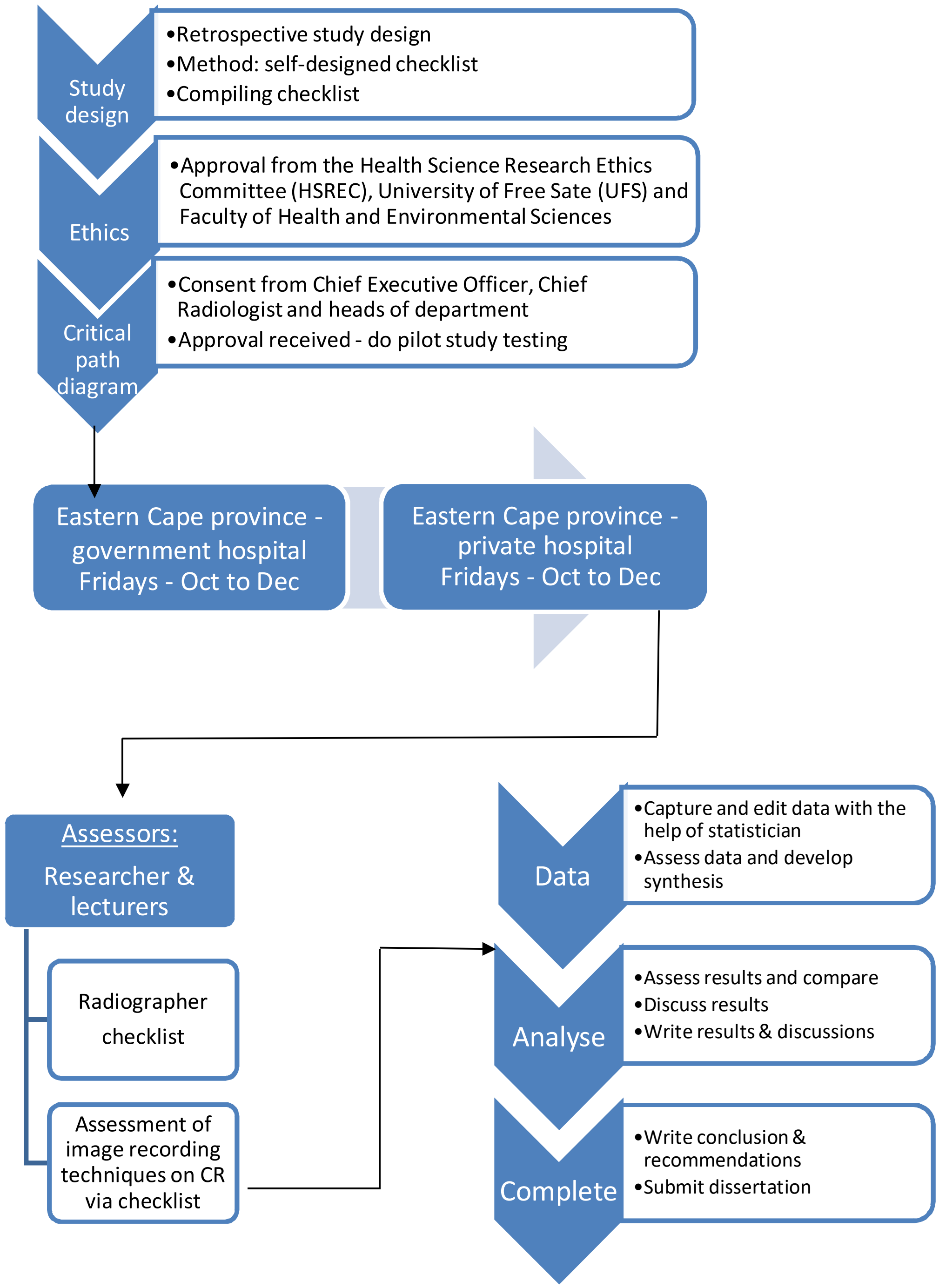


Figure 1.1 Schematic overview of the study (Compiled by the researcher, Nel 2017).

1.8 OVERVIEW OF THE CHAPTERS

The section that follows provides an overview of the different chapters in the dissertation.

Chapter 1: Orientation to the study

Chapter 1 describes the study background and presents the motive for the research question. The chapter also outlines the aims, objectives, purpose and rationale of the study, as well as the underlying assumptions.

Chapter 2: Radiographic image recording techniques

Chapter 2 presents the theoretical framework within which the research was conducted. The chapter includes a brief history explaining the reasons for the change from conventional film-screen radiography to CR. Technical aspects of CR image acquisition are explained as well as how literature relevant to the study was sourced. The main conclusions and findings of the literature review relevant to the empirical part of the study are also summarised.

Chapter 3: Research design and methodology

Chapter 3 documents the design and methodology followed during the fieldwork. The research design, materials and methods used are discussed and the data collection and statistical analysis are also described. This is followed by a discussion of the design, permission, sample, data collection, data analysis and ethics.

Chapter 4: Results and discussion

Chapter 4 documents the research findings which are presented, analysed, interpreted and discussed. The retrospective analysis of CR image recording techniques is used to inform the recommendations of the study.

Chapter 5: Conclusion, limitations and recommendations

Chapter 5 is the concluding chapter, which presents the outcomes of the study. This section includes limitations of the study, a summary of the findings stated in conclusions of the research as well as the recommendations accordingly.

1.9 SUMMARY

The first chapter provides the orientation, background and context to the research problem of the study. In this study, the image recording techniques of chest (PA/AP and LAT) and abdominal (erect and supine) images from two hospitals were retrospectively assessed. A self-designed checklist assisted the three assessors in evaluating the image recording techniques used by the diagnostic radiographers when producing the images. The overall goal, aim and objectives of the study were provided as well as an overview of each chapter of the dissertation. The next chapter presents the theoretical framework, which forms the basis of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

As a consequence of the shift from conventional film-screen to CR systems in SA, diagnostic radiographers have experienced technological changes in their working environment. With film-screen radiography diagnostic radiographers were responsible not only for positioning patients to take a radiograph of the best quality possible, but they were also accountable for image processing in a darkroom with the use of chemicals. Diagnostic radiographers were not able to manipulate the fixed image once radiation exposure had taken place, which is currently possible with CR and DR.

Chapter 2 reviews literature on conventional film-screen radiography, CR, digital image critiques and the technical aspects of working with CR. The literature is sourced from various articles in medical journals, which were obtained from the Internet using search engines that included: Science Direct, Google Scholar and PubMed. The key words that were used in the research included CR and film-screen radiography imaging, optimisation of image quality and EI. Other sources include online literature and printed literature between 1998 and 2018. Most of these were found on electronic databases such as Biomedical Imaging and Intervention®, Medscape®, SA Journal of Radiology® and Medical Radiation Science®. The theoretical framework of Chapter 2 is presented in Figure 2.1 below.

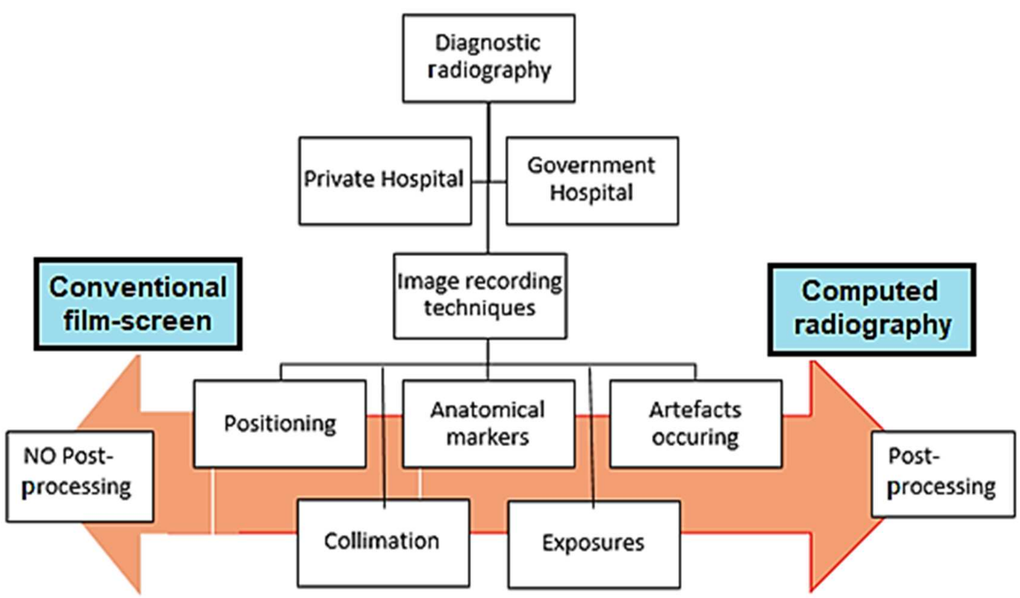


Figure 2.1: Theoretical framework of Chapter 2 (Compiled by the researcher, Nel 2017).

The literature review establishes the scope of the project insofar as it examines information related to the study objectives and focuses on important aspects of the study. The information gleaned from the literature review is also used as a conceptual framework to create the research tool, namely the checklist. There is scant literature on the particular methodology used in this study however, there are some references to similar studies in other fields.

The goal of the study is to examine CR image quality prior to post-processing and to ensure that optimal radiographic image recording techniques are followed when using CR image acquisition systems. Analysing similar studies has yielded valuable insights on CR image recording techniques in order to assess if techniques such as collimation, placing of personal anatomical markers, artefacts avoidance occurring and the achievement of acceptable EI values are currently being used in the private and government hospitals of the Eastern Cape province of South Africa.

2.2 RADIOGRAPHIC IMAGING ACQUISITION PROCESS

Digital imaging was first used in the 1970s with the introduction of the computed tomography (CT) scanner by Godfrey Hounsfield. In the decades since then, other imaging modalities have also been digitised (Carter & Vealé, 2010: 4). As indicated by Carter and Vealé (2010: 4), CR systems have been in use since the 1980s. Pongnapang (2005: 1) confirms that in the two decades before 2005, there was an evolution from conventional film radiography to modern CR imaging. In digital radiography, the image is converted into numerical format, which is a consequence of how the image is captured, converted and viewed. Declared by authors Schaefer-Prokop*, et al.* (2008: 1818), was that chest imaging (projections chosen for the current study) still remain the core of imaging. The reason for this statement is that the speed and interpretation of acquirement, low cost and low radiation of digital radiographic imaging are great advantages. Taking the core imaging approach into account, plain radiographs of the abdomen provide a less sensitive diagnostic study for abdominal organs, and are therefore included in the study (Pregerson, 2010: online). As a result, it is essential for this current study to assess the image recording techniques of chest and abdominal data, prior to post-processing.

The following section provides a detailed discussion of the image recording technique principles of both film-screen radiography and CR. In section 2.2.1 below, the importance of each film-screen image recording technique is described as well as its effect on image quality, how the application of this technique compares to CR and how its effect can be augmented using CR post-processing.

2.2.1 Workflow using film-screen radiography

It is significant to revisit the methods of the traditional way of capturing chest and abdominal radiographic images on film-screen, since no post-processing benefits were derived. A traditional x-ray room with a table, wall Bucky and cassettes are required for both conventional film-screen radiography and CR (Carter & Vealé, 2010: 64). Adequate capturing of film-screen radiography did involve proper training of radiographers since small errors in radiographic image recording technique could permanently affect the quality adequate image production (Alexander, 2016: 54). For conventional film-screen radiography, the equipment and processes described below are important in order to create high-quality radiographic chest and abdominal images, which require the demonstration of different structures and tissue with high contrast. The importance of these processes indicate the traditional methods of chest and abdominal image production, which still need to be applied to modern CR radiography. The following sections will elaborate on the conventional film-screen imaging techniques of the chest and abdominal projections in the current study.

2.2.1.1 Film screen image capturing

When the x-rays strike the intensifying screen, light is produced. The intensifying screens can have single (slow-screen) or double (fast screen) emulsion on the sides of the screen. Single emulsion produces far more detailed images than the less detailed double emulsion layer intensifying screen (Bushong, 2012: 210). The light photons and x-ray photons interact with the silver halide grains in the film emulsion and the image produced is not only influenced by anatomy and pathology but also by the radiographic technique used. The use of the film-screen technique therefore depends on the most optimal exposure to achieve a faultless radiographic image before it is ready for processing. Contrast is influenced by kilovoltage (kV) while milliAmpere-seconds (mAs) influences density. Correct centring in positioning and the use of anatomical markers are also essential. Image geometry, such as the focal spot size, object image distance (OID), focus-film distance (FFD) and source-image distance (SID) must be correct in order to obtain adequate image sharpness. Scatter radiation is minimised by the use of collimation, the use of grids (secondary grids doing mobile images), which absorb scattered rays (ASRT, 2012: 10 & 11).

2.2.1.2 Film-screen latent image creation

The second step is the chemical process that converts the latent image into a visible image with a range of densities or shades of grey (Fauber, 2013: 156). Exposed film is first transported through a system with developer solution. Thereafter, the film is transported to a fixing solution where the unexposed silver halide crystals are dissolved and washed off to remove processing products. Lastly, the film is dried to remove all water. Processing conditions such as developer and fixer concentration, temperatures and the temperature of the water used to wash off the developer must be close to the developer and fixer solution since they influence image quality by avoiding reticulation (uneven expansion and contractions of the emulsion layer) (Singh & Rao, 2000: online). Quality Control (QC) programmes ensure that the diagnostic images are of high quality.

2.2.1.3 Film-screen image viewing

Medical images are recorded on transparent film, which can be easily viewed by placing a light behind them (Sprawls, 2018: 65). These transparent films can then be viewed on a flat illuminated surface, known as a viewing box. When a radiograph emerges from the film processor, the image is permanent and cannot be changed. It is therefore important that all factors associated with the production of the image are adjusted to produce optimum image quality; this includes viewing box illumination.

2.2.2 Workflow using CR

A common CR imaging workflow is similar to a conventional one except where CR refers to the use of a photostimulable phosphor detector (PSP) system, which is housed in a cassette similar to a film-screen cassette (Bushberg *et al*., 2012: 214). As mentioned in the previous section (cf. 2.2.1), CR also requires a traditional x-ray room with a table, wall Bucky and cassettes (Carter & Vealé, 2010: 64). When using CR, the following equipment and processes are important in creating a high-quality radiograph concerned with the imaging techniques of the chest and abdominal projections, which is pertinent for assessment in the current study.

2.2.2.1 CR image capturing

In CR, the IP contains barium fluorohalide crystals of which its electrons are elevated to a higher potential difference orbital when they interact with the attenuated x-ray beam. Rather than emitting light when x-rays interact with it, the IP stores the x-ray energy in proportion to the intensity it receives (Carter & Vealé, 2010: 66).

2.2.2.2 CR latent image creation

Following exposure, the cassette is placed in a reader that removes the IP and scans it with a laser to release the electrons that were raised to a higher potential energy level. A red laser light scans across the whole IP, which is necessary to energise and de-excite the trapped electrons. The photostimulated luminescence produced is then converted into an electrical signal and digitised by an analog-to-digital converter (Bushberg *et al.,* 2012: 214). The electronic signal, which is digitised is then stored and recorded as a matrix of small ‘picture elements’ called pixels (Fauber, 2013: 65).

Most manufacturers employ an exposure index/indicator (EI) value for CR imaging to indicate the average incident exposure delivered to the IP after x-ray transmission through the patient. Mean pixel values are used to calculate the EI. The EI is important for the verification of proper radiographic technique since positioning, exposure, collimation and the size of cassettes all play a vital role (CRCPD, 2008: online). EI is discussed further in section 2.3.3.

2.2.2.3 CR image viewing

CR uses monitors to view the radiographic data. Every reader is connected to a computer on which data can be viewed and manipulated (Fauber, 2013: 174). The Agfa NX viewing workstation is used in both the hospitals under study. All images that are identified on a NX workstation appear on the monitor and can be stored locally on the NX drive or forwarded to an archive (Agfa Healthcare NV, 2014: 3). Beneficially, time is saved with the use of CR systems, since chest and abdomen images (all digital images though) can be quickly retrieved by patients' physicians or other hospitals in electronic format (Orenstein, 2018: 22).

Discussed in section 2.2.2.2, pixel size plays an important role in the display/resolution and the storage of radiographic information on the image plate. Varying depths of contrast and spatial resolution, chest and abdominal images used for assessment in the study requires a good degree of differentiation between radiographic elements. Image quality refers to the image detail, as illustrated below. In Figure 2.2 below, the role of pixel size and bites/pixels in the appearance of the radiographic image is demonstrated.

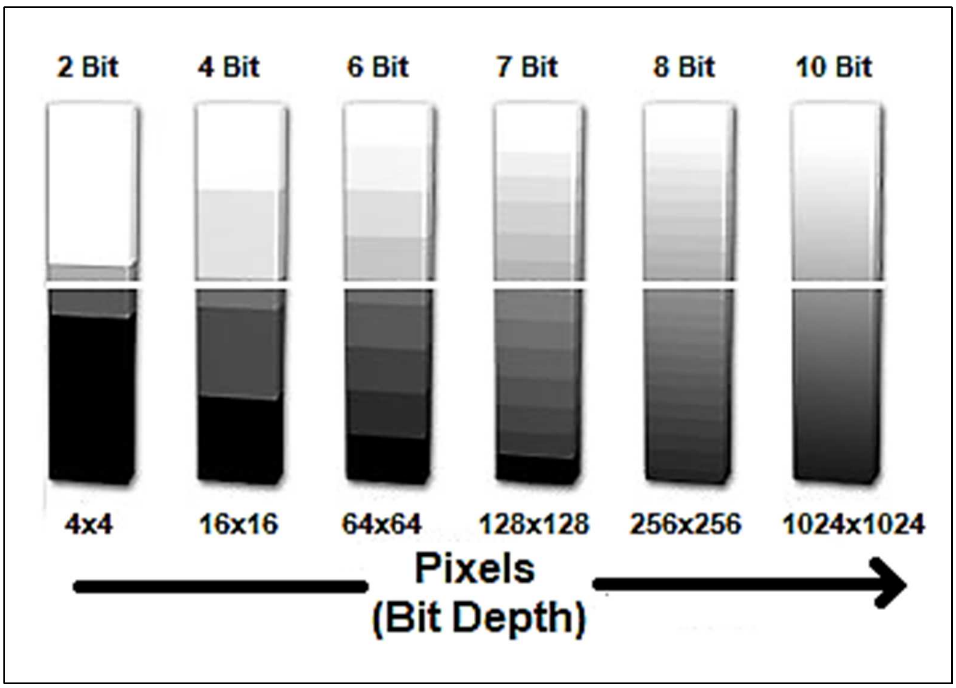


Figure 2.2: The effect of pixel size on resolution and the effect of bit-depth on image quality (Adapted from Spring & Davidson, 2015: online).

Figure 2.2 illustrates that digital image resolution is improved with a larger matrix size, meaning a greater number of smaller pixels (Fauber, 2013: 65). Pixel size can be changed in CR. In film-screen however, no change can occur due to its fixed crystal size. The greater the matrix size, the greater the spatial resolution and image sharpness (Carlton & Adler, 2013: 325). The figure also shows that more bits result in more shades of grey per pixel.

2.3 CR IMAGE RECORDING TECHNIQUES

Appropriate CR image recording technical factors play an important role in medical imaging, even though technology has improved (Alexander, 2016: 61). Following, is the image recording techniques of exposure factors, histograms, analogue-to-digital exposure indicators and post-processing that will henceforth be discussed.

2.3.1 Exposure factors

It is the responsibility of the radiographer to select the most appropriate exposure factors (mAs and kV) in order to produce the diagnostically acceptable chest and abdominal images. In film-screen radiography, kV has an influence on image contrast (cf. 2.2.1.1) whereas the contrast-to-noise ratio (CNR) metric is used to evaluate the degradation of contrast and is an estimate of noise in the CR image (Desai, Singh & Valentino, 2010: online). MilliAmpere-seconds (mAs) are proportional to the density of the images in film-screen, which is different in the use of CR. Desai *et al*. (2010: online) indicate that the signal-to-noise ratio (SNR), which measures the true signal to noise is proportional to density in CR. CR's broad exposure latitude allows for a range of exposures that produce densities within the diagnostic range for clinical radiographic purposes (Carlton & Adler, 2013: 305). The outcomes of the broad exposure latitude response of digital radiography, relating to CR in particular, are illustrated in Figure 2.3 below. Figure 2.3 illustrates the characteristic curve that demonstrates the comparison to film-screen response with the function of an incident exposure.

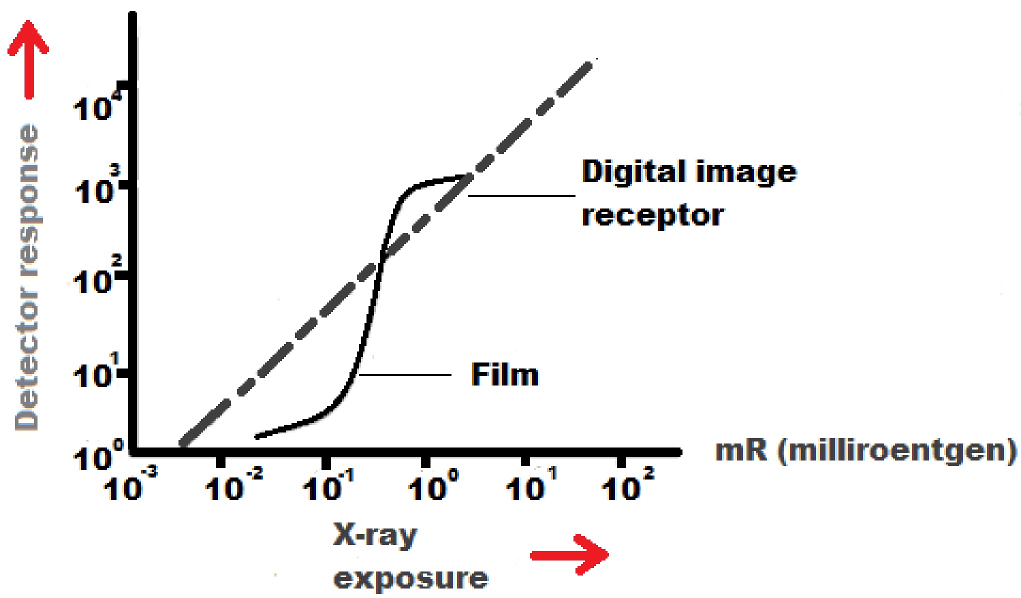


Figure 2.3: Characteristic curve response of film-screen and digital radiography detectors (Adapted from Fauber, 2013: 158).

As shown in Figure 2.3, film-screen radiography has a limited dynamic exposure range compared to digital image receptors (Fauber, 2013: 158). The advantage of CR is therefore its large, dynamic exposure range, digital format, portability and post-processing capability (Pongnapang, 2005: online). The broad dynamic range of CR is convenient for the presentation of chest and abdominal images in relation to demonstrating the differences between specific tissue absorptions (e.g. bone vs. air vs. soft tissue).

The exposure response of film-screen and CR differ (Carlton & Adler, 2013: 340). This difference is illustrated in Figure 2.3. Film-screen has a non-linear response, with a narrow exposure latitude whereas CR's is linear with a wide exposure latitude. Contrast in both systems is regulated with kV. Film-screen images have a film-response curve to demonstrate the influence whereas CR uses the benefit of look-up-tables (LUT). Density within both systems is influenced by variances in mAs. Scatter radiation plays the same role in both systems however, the CR system is more sensitive to low energy levels than the film-screen system. Thus, reducing patient dose by using low mAs increases the likelihood of scatter in both systems. Lastly, noise factors in film-screen are created with low mAs in fast screens only, whereas inadequate use of mAs causes noise in CR images (Carlton & Adler, 2013: 340).

Huda and Abraham (2014: 130) stress that with examinations such as chest and abdominal radiographs, it is essential to reduce exposure latitude. Huda and Abraham (2014) further explain that the broad exposure latitude in CR results in the lung appearing black (with higher exposures being made) and the mediastinum appearing white. High kV exposure reduces the exposure latitude and is therefore used when performing chest radiographs. For each exposure made using CR systems, a histogram of the useful signals is created by the processing unit. These signals are useful in the current research study, since chest (PA/AP and LAT) images that are assessed, need to show accurate high kV exposures used. However, there is controversy since lower kV needs to be used with abdominal images to increase the image contrast. The reason for this increase in contrast is due to the fact that soft tissue organs that require grey-scale differences are of concern.

2.3.2 Histograms

The default method for determining the useful signal for most CR scanners requires the construction of a grey-scale histogram of the image. This is a graph with the signal value on the x-axis and the relative occurrence on the y-axis, as shown in Figure 2.4 that follows (Siegel & Kolodner, 1999: 146). The histogram represents all the different greyscales (pixels) in the image as a consequence of what happened in the anatomy (voxel). What happens if the anatomy is additionally dependent on the exposure given by the radiographer? As explained by Shetty, Barthur, Kambadakone, Narayanan and Kv (2011: 37), the first step in acquisition processing when using CR is made by the operator, who selects which examination projection the IP contains. The first task of the CR processing is pattern recognition in order to determine the orientation of projections in the raw digital data according to the processing algorithm selected. Within an exposure field, it is important for the CR scanner to distinguish the useful region of the image by locating the edges of collimation. This is known as collimation detection.

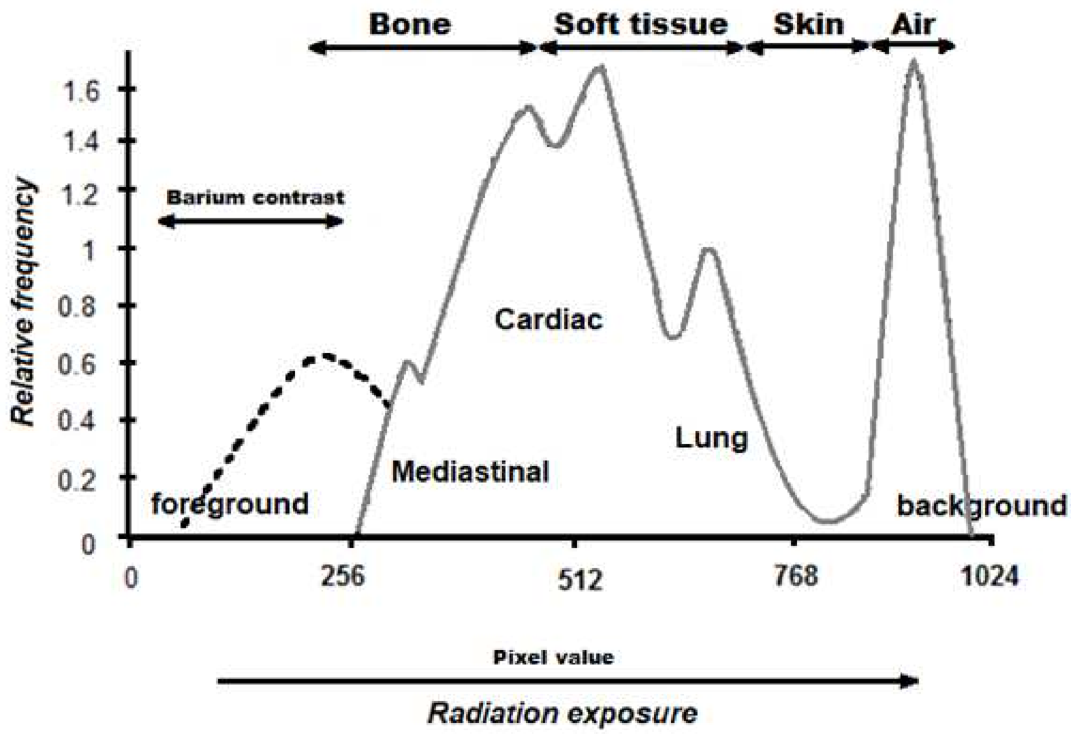


Figure 2.4: Image histogram displaying the frequencies compared to radiation exposure in the region of interest (Adapted from Flynn, 2008: online).

Histogram analysis involves the information that is important on the histogram, which is determined by the values of interest (VOI). The VOI is different for each body part under examination. Illustrated in Figure 2.4, is an example that shows that 'air pixel' value in chest images vary significantly from abdominal 'soft tissue pixel value'. As explained by Carlton and Adler (2013: 350), the CR system has a LUT, which has the appropriate contrast (histogram) for each body part. Therefore, it is important that the correct LUT is selected as the CR systems need to identify what type of examination is to be performed before the image can be acquired, processed and displayed. Images created are compared to the LUT information (ideal histogram) and if there is a discrepancy, the image histogram can be electronically adjusted to match the LUT histogram, thereby improving image quality.

Histogram errors can occur when an image does not fit the parameters that were used for the reference histogram. In other words, the error is due to incorrect pre-processing histogram selection. An example of this error occurs when a hand parameter is selected when, in actual fact, an abdomen is being examined. It is therefore important to determine that the correct part has been selected when analysing chest and abdominal images. If an incorrect part has been selected, the appropriate density and contrast will not be displayed, since the computer does not recognise the data and will result in an inaccurate EI number (Carlton & Adler, 2013: 350).

Thus, the importance of discussing histogram errors in this study was to ensure that the correct body parts were recognised, being chest (PA/AP and LAT) and abdominal (erect and supine) images that are intended for assessment. The investigation of histogram errors will therefore show the correct contrast in the region of interest (ROI). Collimation edges and elimination of scatter outside the collimation had to be recognised effectively to create an optimal histogram. In theory presented by Arnold (2008, online), he states that if chest and abdominal images failed recognition of the system, images would result in being too bright or too dark.

2.3.3 Analogue-to-digital exposure indicators

Seibert and Morin (2011: 573) explain that the exposure index (EI) is a method whereby digital radiography manufacturers provide feedback to diagnostic radiographers regarding the estimated exposure on the CR (digital) detector. This method can be used as a substitute for the image SNR to give an indirect indication of digital image quality. It is important for diagnostic radiographers to understand the use of the EI values provided, after radiation is given to patients. EI is used as the exposure indicator in the CR system specifically investigated in this study. EI is a numeric value calculated from the signal that is generated from the conversion of light given off from the IP after radiation (Carter & Vealé, 2010: 86). Lopes and Domingos (2012: online), specify that “despite the fact that EI doesn’t relate directly to the patient dose, it is of the utmost importance to monitor and evaluate EI in order to optimise the radiation dose in each exposure”. It is therefore important to explain the various concepts of EI concerning chest (PA/AP and LAT) and abdominal (erect and supine) imaging in this research study, as outlined in the following sections.

According to Fauber (2013: 229), the EI value in CR represents the exposure level to the image plate (the digital detector); the values used are vendor-specific. Table 2.1 following hereafter lists common CR exposure indicator values and their relationship to exposure intensity for different vendors, namely, Fuji and Konica, Kodak and Agfa. As noted in section 2.2.2.3, Agfa is the vendor used in both hospitals and therefore these vendors’ chest and abdominal images were utilised for this research study. AGFA originally used the LgM but recently EI is utilised as the standardised exposure value for all digital systems (Cohen, Cooper, Piersall & Apgar, 2010: 7).

Table 2.1: Computed radiography vendor-specific exposure indicators (Adapted from Fauber, 2013: 229).

Vendor	Exposure Indicator	Value = 1 mR exposure	2 x Exposure	½ Exposure
Fuji and Konica	Sensitivity (S)	200	100	400
Kodak	Exposure index (EI)	2000	2300	1700
Agfa (from the past)	Log median value (LgM)	2.5	2.8	2.2
Agfa (presently)	EI	2000	2300	1700

As shown in the aforementioned Table 2.1, exposure indicators differ for the three vendors. The Fuji and Konica vendor uses the Sensitivity (S) detector dose indicator, whereas Kodak uses the exposure index (EI) dose indicator and Agfa the log median value (LgM). Agfa CR can use log median exposure or the exposure index (EI), as noted in this study, which specifically assesses chest (PA/AP and LAT) and abdominal (erect and supine) images. Agfa's LgM is based on a log system; a change of 0.3 means the dose is changed by a factor of 2, analogous to doubling or halving the exposure (Carlton & Adler, 2013: 335). The two hospitals in this study use Agfa systems, presenting exposure feedback through EI values (see Table 2.1). Carlton and Adler (2013: 335) also mention that Agfa also has a 'speed class' of 50, 100, and 200 and 400, which is similar to conventional film-screen radiography. The exposure indicator is programmed into the algorithm that is selected before the plate is put into the reader. In the study, the EI values of the chest (PA/AP and LAT) and abdominal (erect and supine) images were captured to indicate the relationship to radiographic exposure.

Three parameters exist namely, EI, target exposure index (TEI) and deviation index (DI). The TEI is the reference exposure obtained when an image is optimally exposed (Don, *et al.*, 2010: online). Deviation index is important since it indicates whether the radiographic technique is appropriate for the specific body part and whether an optimal image will be attained (Seibert & Morin, 2011: 579). As stated by Don *et al*. (2010: online), DI quantifies how much the actual EI varies from the TEI.

Thus, as explained by Seibert and Morin (2011: 579), DI provides feedback to the operator with:

- a value that is equal to zero when the appropriate exposure to the detector has been achieved;
- a negative number when underexposure has occurred; and
- a positive number when overexposure has occurred.

In an ideal situation where EI and TEI is the same, the DI will be zero (Don *et al.,* 2010: online). Table 2.2 that follows hereafter, illustrates that a DI value of +1 indicates overexposure equal to 25% more than the target exposure to the detector, while a value of -1 indicates underexposure equal to 25% less than desired. DI values of +3 and -3 indicate exposure that is two times more and less than the target exposure, respectively (Seibert & Morin, 2011: 579).

Table 2.2: Agfa's deviation index, EI with deviation index values (Adapted from Bowman, 2012: online).

Examinations	EI - Deviation Index (DI)			Target EI	EI + Deviation Index (DI)		
Speed Class Free	-3	-2	-1	0	+1	+2	+3
Extremities No Bucky	-100%	-60%	-25%	1000	+25%	+60%	+100%
All Chest X-rays	-100%	-60%	-25%	500	+25%	+60%	+100%
Abdominal & in Bucky exams	-100%	-60%	-25%	250	+25%	+60%	+100%

Table 2.3 that follows provides an overview of the aforementioned discussion regarding exposure.

Table 2.3 Deviation Index and use with clinical images (Adapted from Don *et al.,* 2010: online).

DI	Exposure	Action
>+ 3	> 2 times overexposure	Report to management, repeat if image "burned out"
+1.0 to + 3.0	Overexposure	Repeat if image "burned out"
-0.5 to + 0.5	**=**	**Target exposure range**
-1.0 to -3.0	Underexposed	Consult radiologist for repeat
< -3.0	< ½ times underexposed	Repeat

Don *et al.* (2010: online), presented images (refer Figure 2.5) obtained on an Agfa CR system using their exposure monitoring quality assurance software with visual opinion. The TEI for the chest radiograph in Figure 2.5 is 450. In image A, 60 kV and 1 mAs were used, which produced an EI of 479 and a DI of 0.3 that is within the acceptable range. Hence, the indicator in Figure 2.5 is green. In image B, the mAs were increased to 2.5 mAs, which produced an EI of 1258, where the DI increased to 4.5, thereby indicating a higher than acceptable exposure. Hence, the indicator in Figure 2.5 is yellow and the image was flagged for review. In image C of Figure 2.5, the mAs were decreased to 0.25 mAs, where the EI resulted in 102, and the DI decreased to -6.4. As seen, image noise is visible and the indicator is red. Image C should also be reviewed with a radiologist to determine if a repeat examination is needed. In this study, it proved to be an excellent indicator for radiographers who are observing whether their chest (PA/AP and LAT) and abdominal (erect and supine) images were in the correct exposure "range" before post-processing.

Figure 2.5: A three image illustration of the principles from Don *et al*., regarding the graphic dose bar graph illustrating the green, yellow and red signifiers: A - within the accepted range; B - higher than acceptable exposure; C – extremely low exposure resulting in image noise (Principles from Don *et al*., 2010: online).

In a study on exposure by Warren-Forward, *et al.* (2007: 28), overexposure or underexposure can easily be determined in film-screen radiography by checking whether an image is 'too dark' or 'too light'. In CR, on the other hand, there is greater flexibility in selecting exposure for an examination. This can lead to incorrect radiographic exposure since over- and under-exposure may be concealed.

'Exposure creep' refers to "the risk of increasing patient dose, possibly without knowing it" through an increase in exposure over time when using CR (Seeram, *et al*., 2013: 331). This phenomenon occurs as diagnostic radiographers tend to increase the exposure factors to minimise the occurrence of quantum noise. Gibson and Davidson (2011: 458-62) conducted a study on the occurrence of exposure creep and confirm its existence. The researchers recorded the EI values of chest x-ray images produced over a 29-month period. Over this period, a total of 17 678 intensive and critical care unit (ICCU) chest x-ray images and 69 327 emergency department chest x-ray examinations were evaluated for over- and under-exposure. The chest x-ray EI values were compared to the radiology department optimal EI range of 1 400 to 1 800. In the ICCU a significant increase (p-value= 0.023) in EI values from the beginning to the end of the evaluation was noted. No such trend was seen in the emergency department EI values (p-value = 0.120). The study therefore found that exposure creep was present. Consequently, for the purposes of this study, it was particularly important to investigate the effect of exposure factors on EI values.

Casey (2014: online) points out that exposure creep is now on the list of healthcare hazards issued annually by a non-profit organisation, the Economic Cycle Research Institute (ECRI). Exposure creep develops over time as diagnostic radiographers try to improve image quality (Casey, 2014: online). Exposure creep is of particular concern in digital x-rays, since digital (CR) has a wider dynamic range than film-screen radiography. This range reduces the likelihood of repeat exams, which itself may cause higher radiation exposure. Casey (2014: online) explains that too much radiation was administered to patients. This study assesses the EI in radiographic images at two hospitals to determine exposure of patients to radiation as well as the radiographic techniques used.

2.3.3.1 Factors that influence EI

Factors that influence the EI of CR differ a great deal from conventional film-screen radiography, although some of the same factors do apply. All of these factors, as set out hereafter, were included in the checklist that was used to assess the chest (PA/AP and LAT) and abdomen (erect and supine) images in this study. Carter and Vealé (2010: 80-87) categorise these factors as follow:

a) **Part selection before processing**
Selecting a certain body part informs the computer how to process the image, creating the expected appearance as a final outcome of the image (Enfinger, 2015: 57). As noted by Enfinger (2015: 57), the scale of contrast is manipulated during processing to take on the 'optimum' features of a diagnostic x-ray (Enfinger, 2015: 57). Each body part has its own structured algorithm in its LUT, which establishes the EI value for each part selected (cf. 2.3.2).

b) **Technical factors – kV and mA, distance and time**
Diagnostic radiographers must keep kV to an optimum range for particular parts of the body and the mA as the controlling factor (Carlton & Adler, 2013: 389). As stated in section 2.3.1, kV is proportional to CNR in CR, whereas mAs is to SNR. EI is proportional to the SNR squared and can be related to image quality (Mothiram, Brennan, Lewis, Moran & Robinson, 2014: 113). Therefore, EI values can be increased or decreased with the use of technical factors.

Diagnostic radiographers should keep the time of exposure to radiation as short as possible since the amount of exposure is directly proportional to the time of exposure. Distance between the source of radiation will decrease the amount of radiation exposure that is received (Papp, 2011: 30). Thus, if distance increases, exposure decreases, resulting in a decrease in EI value.

c) **Equipment selection – Image plate selection, grid selection**
The size of the cassette (covering the IP) per examination is important in order to centre anatomical parts to the selected cassette. Grid selection is also important in order to absorb scatter exiting the patient and increase radiographic contrast (ASRT, 2012: 11). Therefore, as more radiation reaches the image plate due to scatter, the processing algorithm will produce a low-contrast image, leading to an increase in EI value (cf. 2.3.2).

d) **Collimation**
Collimation reduces the possibility of processing errors of the software (ASRT 2012: 10). Incorrect collimation or no collimation at all, can lead to off-focus (where the intended area of the chest and abdomen images are not appropriately positioned or centred to the IP) as well as an increased proportion of scattered photons in the study's histogram records that were assessed. As stated by Mothiram *et al.* (2014: 115), changes in collimation and field size considerably alter the EI. Collimating the ROI reduces the overall integral dose to the patient and thus minimises the radiation risk. If an area is less irradiated (collimated) it will result in a lesser incidence of scatter on the detector, which will have a decrease in EI value.

e) **Supplementary factors**: **positioning and centring, histogram analysis and scatter/fog.**
Inappropriate positioning and centering will produce an inaccurate result in the EI number, compared to the more spot-on positioning and centering, being the direction of the central ray of the x-ray beam to its point of incidence on the area of the examination. Scatter radiation, mentioned above, gives rise to low contrast and EI value.

According to Pongnapang (2005: 2), other factors such as taking two projections on one cassette also affect the EI. This technique is ill-suited to CR since double or multiple exposures on a single IP can lead to a failure of the image processing software to detect the image boundary. Even so, this concept is not applicable to the current study since two chest or abdominal image projections cannot 'fit' onto one cassette, due to the human dimensions. In film-screen radiography, the photographic and geometric factors of contrast, density, distortion and spatial resolution are permanent (Singh & Rao, 2000: online), whereas CR allows post-processing to change these factors. This post-processing function is discussed in the following section.

2.3.4 Post-processing

In CR imaging post-processing can be carried out using specific computer software available to diagnostic radiographers and radiologists. The post-processing functions enable the manual manipulation of the displayed image, which allows the operator to adjust a number of presentation features of the image to enhance its diagnostic value (Fauber, 2013: 177).

Contrast and contrast resolution are important characteristics of image quality in film-screen radiography. Contrast in CR and film-screen radiography arises from the areas of light, dark and shades of grey on the x-ray image. With digital systems, contrast can be manipulated using windowing and levelling. Window level is defined by Fauber (2013: 317) as setting the midpoint (centre) of the range of brightness visible in the digital image. This means that an increase in the window level increases the image brightness and a decrease in the window level decreases the image brightness. The window selection is an interactive, grey-scale process (Siegel & Kolodner, 1999: 61). Window width, on the other hand, is a control that adjusts the radiographic contrast. A narrow window width decreases the range of brightness levels and increases contrast, whereas a wider window width increases the range of brightness levels and reduces contrast (Fauber, 2013: 179). Important relationships evolve between window level and brightness according to Fauber (2013: 178), who maintains that there is a direct relationship between window level and image brightness on the display monitor.

Achieving a good signal-to-noise ratio (SNR) in the ROI with CR will yield a quality digital image, similar to the contrast and resolution achieved for film images. SNR is defined by Fauber (2013: 316) as the strength of the radiation exposure compared with the amount of noise (background information that the imaging receptor receives) apparent in a digital image. SNR depends on the mAs given, since it influences the amount of quantum mottle. Radiographic noise occurring in film-screen radiography is influenced by structure mottle, quantum mottle and scatter radiation. The various ways by which noise can be reduced in post-processing can be defined as 'image enhancement'. The image processing operations are controlled by LUT, which are assigned a value in accordance with the examination type. As the images are identified at a specific workstation, according to the type of examination that was done, they fall into the given category. These parameter values are estimated by heuristic algorithms (Vuylsteke, *et al.*, 1999: 87). In this study, predefined parameter values for chest (PA/AP and LAT) and abdominal (erect and supine) x-rays are stored in LUT.

The factors outlined in the aforementioned indicate that diagnostic radiographers' techniques can be compromised by the use of post-processing. Post-processing can change the quality and EI value on images, thereby altering the original image, which masks the incorrect use of image techniques and image rejection. An imperative aspect of this study was to assess the raw chest (PA/AP and LAT) and abdominal (erect and supine) image data before post-processing. The raw data of chest (PA/AP and LAT) and abdominal (erect and supine) images establish the particular image recording techniques used in this study.

2.4 RADIATION DOSE

The Radiological Society of South Africa's (RSSA) code of conduct regarding radiation safety ensures that the radiation dosage that patients are exposed to is minimised and does not exceed the prescribed safety levels (RSSA, 2002: online). In a study, Herbst and Fick (2012: 53) indicate that more than 80% of overexposure, which leads to an increase in radiation dose (quantity) to the patient, is generally caused by human error. These human errors include poor collimation, not applying radiation protection while performing the x-ray examination of the patient and not using the exposure chart to select the correct exposure. When living organisms (such as human beings) suffer biological damage as a result of exposure to radiation, the effects of this exposure are known as 'somatic effects'. Depending on the length of time from the moment of irradiation to the first appearance of symptoms of radiation damage, the effects are classified as either early or late somatic effects (Statkiewicz-Sherer, Visconti & Ritenour, 1998: 115-116).

Radiation dose optimisation in CR imaging in this research study relates to the radiographic technique used during the production of chest (PA/AP and LAT) and abdominal (erect and supine) images. From the aforementioned discussion, it is clear that it is often necessary to evaluate and justify the compromise made between image quality and radiation dosage to the patient. The use of radiation for diagnostic purposes needs to be justified, optimised and dose limits should be set (Seeram *et al.,* 2013: 331-332). EI value assessment was therefore included in this study in order to evaluate exposures; either as overexposure, underexposure or in range.

2.4.1 Radiation protection

The goal of radiation protection in chest and abdomen images is to limit human exposure to ionising radiation. Limiting human exposure should be to such a degree that it is acceptable in relation to the benefit gained from the exposure (Carlton & Adler, 2013: 142). As observed by Statkiewicz-Sherer *et al.* (1998: 148), patient exposure can be limited by proper immobilisation, the use of beam-limited devices, correct filtration, the use of gonad and other types of shielding, appropriate exposure, good radiographic processing techniques, effective communication and minimising repeat radiographs. The goal of radiation protection is therefore to minimise the probability of stochastic risks and to prevent the occurrence of deterministic effects (Seeram *et al.,* 2013: 331).

The various factors mentioned above indicate how optimal chest (PA/AP and LAT) and abdominal (erect and supine) images can be created and how image recording techniques used with CR can be rendered safer and more efficient. Factors affecting EI were addressed and discussed in section 2.3.3.1,. CR offers seemingly better control over this compromise however, this advantage can be countered by the 'double-edged sword effect', which is discussed in the following section.

2.5 DOUBLE-EDGED SWORD EFFECT

The double-edged sword is an analogy used to describe the dual nature of CR: there are advantages to using CR however, if misused or applied incorrectly, these advantages can have negative consequences (cf. 1.2). Therefore, the use of CR has both advantages and disadvantages, which should be taken into account. Hence, it is referred to as the 'double-edged sword effect' (Siegel & Kolodner, 1999: 148). The advantages of CR include broad exposure latitude, ability for post-processing (manipulation of radiographic contrast and brightness) and multiple viewing options (ICRP, 2004: 34). CR often requires fewer retakes that may result from under- or over-exposure. Due to the broad exposure latitude, overexposed images may not necessarily appear dark while underexposed images may not necessarily appear light. Diagnostic radiographers therefore need to monitor the EI value as a guide for proper exposure techniques (Fauber, 2013: 229). CR is more flexible in terms of correct exposure factors as it allows images to be manipulated. However, this may mask the presence of under- or over-exposure on the original CR image (Siegel & Kolodner, 1999: 148). Thus, images produced at a radiation exposure which is higher than necessary, have less noise and improved diagnostic quality, at the expense of the patient being overexposed (Fauber 2013: 154).

Images can be enhanced digitally to aid interpretation. By adjusting image brightness and/or contrast, a wide range of thicknesses may be examined in one exposure, which can lead to diagnostic radiographers avoiding noise in images (avoiding low patient exposure) (Williams *et al.,* 2007: 10). Therefore, overexposed CR images may appear as if a correct technique had been used. As stated by Towbin and Owen (2012: online), this double-edged sword effect is illustrated by the phenomenon of exposure creep, where the use of high exposures eliminates the need for a second exposure.

CR allows for annotations (erect, supine, decubitus etc.) to be placed after processing. CR therefore also allows radiographers to apply an anatomical marker, which is an advantage, but legally anatomical markers need to be placed before exposure (Johnson, 2014: 1). The reason for this is that mistakes as a result of placing the wrong marker on the wrong side of the patient, should at all times be prevented. Patient safety is the primary concern and anatomical markers should therefore be used persistently, regardless of the opportunity to add them post exposure. Radiographers misplacing the marker during post-processing annotation can be held "legally responsible and accountable for the results of their professional actions caused by act, negligence [or] omission" (Titley & Cosson, 2014: 42). In short, while examining the patient, a radiographer can literally distinguish the differences between left and right, but during post-processing behind the computer, uncertainty may arise. Therefore, the assessment of anatomical markers was included in this study.

2.6 PREVIOUS STUDIES

Nyathi, Chirwa and Van der Merwe (2010: 1-5) assessed diagnostic radiographers' familiarity with digital radiography in four South African teaching hospitals. In this study, the hospitals were identified as Hospitals A, B, C and D. Questionnaires were designed to collect data from either qualified or student diagnostic radiographers. Experiences and preferences with regard to digital radiography, quality control procedures, patient dose as well as advantages and disadvantages of digital radiography were sought.

The questionnaires presented both closed and open-ended questions. The findings suggested that there is a need for formal education, continuing education and manufacturer training on quality control in the use of modern digital x-ray units (Nyathi *et al.,* 2010: 1-5).

Mothiram, Brennan, Lewis, Moran and Robinson (2014: 112 - 118) commented on EIs in a study, specifically indicating that the advantage of broader exposure latitude in digital imaging (CR & DR) poses a risk for increased exposure to patients if applied incorrectly. By examining the application of EIs, this study seeks to provide diagnostic radiographers with a useful guide to understanding EIs and their correct application in clinical practice. EI can thus be used as a quality assurance (QA) tool to monitor the correct use of equipment and to observe variations in the detector dose (Mothiram *et al.*, 2014:116). This study evaluates the application of EI values in images by assessing the raw data before processing. Thus, actual images taken by diagnostic radiographers were assessed by three assessors in order to prevent diagnostic radiographers from inadvertently 'fixing' their mistakes.

2.7 TECHNICAL CRITERIA FOR CHEST AND ABDOMINAL RADIOGRAPHS

The checklist used in this study is informed and created by utilising the literature reviewed in the previous sections. The radiographer must evaluate the diagnostic and technical quality of all radiographs before submission for radiological review. Therefore, the following technical aspects applied in CR are examined in this study: projection selection, positioning of anatomical parts of the chest or abdomen, collimation, anatomical marker use, artefacts, image quality, EI and histogram errors (cf. 2.3.3.1) (see Appendix A).

The following section discusses the importance of image recording techniques and their effect on image quality, how this technique compares in CR and how its effect can be improved using CR post-processing. Criteria for assessing image recording techniques of chest (PA/AP and LAT) and abdominal (erect and supine) images are also described to illustrate what the researcher and the assessors concentrated on when evaluating the chest (PA/AP and LAT) and abdominal (erect and supine) images during this specific study.

2.7.1 Criteria for assessing image recording techniques of radiographs

In a US study, Jones, Polman, Willis and Shepard (2011: 243-255) investigated the reject and exposure analysis working with CR. The reject analysis programme (RAP) and EI data of the images were collected and analysed over the period of a year. The RAP data were sorted by reason for repetition and body part examined. The study presented a reject rate of all images examined over the period of one year that was mainly due to positioning errors (77.3%) as well as exposure errors or 'incorrect EI' values (9.8%). The reject analysis programme proved to be a powerful tool for quality assurance (Jones *et al.,* 2011: 243-255). In discussions about the study of Jones *et* *al.*, positioning, exposure error, artefacts and patient identification problems were identified as common mistakes made by radiographers. Reject image analysis and exposure analysis reports could be generated automatically to ensure that operators perform their duties more efficiently (Jones *et al.,* 2011: 255).

Bontrager and Lampignano (2014: 30-35) maintain that an image can be of diagnostic value even if it is not perfect. As mentioned prior in the introduction (cf. 2.7), the factors identified for assessment in this study are: correct body part selection at the CR workstation relating to the examination requested, positioning of the anatomical part during examination to the cassette used, collimation, personal anatomical markers used, artefacts, EI values, histogram errors and reasons for repeat radiographs occurring. The criteria being discussed in the following should be evaluated when ascertaining diagnostic value.

Patient identification data should be sufficient to identify the patient under examination. Anatomical boundaries of the part under examination should be shown correctly where collimation did not 'cone off' valuable anatomy. The collimation is vital to reduce scatter, improve image contrast and reduce the area irradiated. Collimation should not be overused at the expense of having to repeat the radiograph.

The correctness of positioning, centring and beam angulation are also very important aspects of good image recording techniques. Any image should be free from distortion, and through observation, should be free from any image artefacts. Any chest or abdominal radiography should be positioned correctly to the cassette, so as to cause minimal unsharpness. As addressed previously (cf. 2.3.3), exposure factors are important. Contrast, density and penetration should be adequate to demonstrate anatomy and the pathology for a diagnosis. Film/image quality involves fogging and artefacts in the image and the radiographer should ensure that this is avoided. Anatomical markers should also be used correctly and visibly placed in order not to obscure any ROI (Bontrager & Lampignano, 2014: 31).

2.7.2 Design of the checklist

The checklist (see Appendix A) was designed based on the contextual material examined in the literature review on achieving quality in CR (Bontrager & Lampignano, 2014; Carlton & Adler, 2013; Carter & Vealé, 2010; Fauber, 2013; Papp, 2011; Siegel & Kolodner, 1999; Wyse, 2011). The checklist is divided into eight elements as set out under separate headings following hereafter. The reason for choosing these specific elements for the purpose of this study is due to the fact that these technical factors influence not only the image quality but also the radiation dose. An analysis of these elements will reveal whether these common image recording techniques have been optimally used or not. Faults in the radiographic equipment, namely cracks, scratches and scuff marks in the IP, debris of CR cassettes, plate reader problems, malfunction of CR scanner causing skipped scan lines, missed pixels and distorted images were also included in the checklist, which is useful for the ongoing quality control of radiographic systems.

Element 1: Part selection on CR workstations

According to Carter & Vealé (2010: 80), the selection of the proper body part on the CR workstation is essential after positioning the patient and exposing the IP (cf. 2.3.3.1).

Element 2: Positioning anatomical parts

Patient positioning is an important factor in image recording techniques. The reason for this is that the positioning performed for radiographic demonstration of specific body parts [being chest (PA/AP, LAT) and abdominal (erect and supine) in the study] should be correctly applied by radiographers performing the examinations in order to produce the images (Bontrager & Lampignano, 2014: 15-17).

Element 3: Collimation

Nyathi (2012: 37) stresses that in dose optimisation in diagnostic radiology, collimation is one of the key elements minimising patient radiation exposure in general radiography examinations. He also suggests that digital radiography should use collimation during exposure of examinations rather than cropping the images during post-processing (Nyathi, 2012: 154).

As observed by Carlton and Adler (cf. 2.3.3.1), incorrect collimation or no collimation can lead to off-focus and scatter in the histogram records of assessed chest and abdomen images in this study. It can also lead to an incorrect EI number (Carlton & Adler, 2013: 350).

Element 4: Anatomical markers

Bontrager and Lampingnano (2014) recommend that 'right' or 'left' anatomical markers should be placed anatomically correctly and visibly before exposure, ensuring that the region of interest is not obscured (Bontrager & Lampignano, 2014: 31). Legally, the radiographer performing the examination must ensure that anatomical markers are always placed in the collimation field in order to satisfy this requirement (Enfinger, 2015: 48).

Element 5: Artefacts

An artefact is anything on a finished radiograph that is not part of the patient's anatomy (Papp, 2011: 180). As concluded by Shetty *et al*. (2010: 37), operator errors have become more evident with the use of the new generation CR systems even though the incidence of software and hardware related artefacts has decreased (Shetty *et al*., 2010: 37).

The CR artefacts listed by Papp (2011: 180-193) were analysed in this study. These artefacts include:

- **Gridlines**

  According to Pongnapang (2005: 4), CR is very sensitive to scattered radiation and it is vital that anti-scattered grids be used, as in conventional radiography. The reason for these grids is to reduce scattered radiation reaching the IP of the CR cassette, thereby improving contrast in radiographic images produced (Bontrager & Lampignano, 2014: 40).

- **IP artefacts**

  IP artefacts refer to any cracks due to damage or ageing, which may cause radiolucency; scratches due to rolling through the processor or scuff marks caused by the removal of IP from the cassette housing during processing. These scuff marks characteristically appear as symmetrical opacities that are either linear or rectangular in shape (Shetty *et al*., 2011: 40).

- **Foreign objects**

  Examples of foreign objects include dirt, objects on patients such as removable or non-removable items, either on or within the patient (Enfinger, 2015: 41) and debris which cause light-coloured specks on the image (Bouye, 2011: 1, 3).

- **Plate reader**

  Extraneous line patterns can occur, which are caused by noise in the plate reader's electronics. The radiographic appearance shows as linear, radiopaque lines on the radiographed images.

- **CR scanner malfunction**

  CR scanner malfunction can cause skipped scan lines, missing pixels or distorted images. Shetty *et al.* (2011: 40) explain that rollers are used within the CR reader to transport the IP for the scanning of latent images by the laser and subsequent erasure by the high-intensity halogen lamp. During this process, the IP is constantly in contact with the rollers, both in and outside the reader. Therefore, the malfunctioning of the rollers causes defective scanning (Shetty *et al*., 2011: 40).

- **Quantum mottle**

  Quantum mottle is the statistical fluctuation in the number of x-ray photons that reach the IP. Quantum mottle is defined as variations in optical density on a radiograph. Huda & Abrahams (2015:1: 29) describe quantum mottle as a blotchy appearance when low mAs are used during exposure in order to decrease patient dose (Huda & Abrahams, 2015: 129).

Element 6: Histogram errors

According to a presentation by Christensen, Jurkiewicz and Kawamura (2015), a histogram is formed when the laser reads the entire IP. Incorrect histograms can influence image quality, e.g. image will be either light or dark (Christensen, Jurkiewicz & Kawamura, 2015: online). Papp (2006:186) confirms that a histogram error is also known as improper image brightness (large density differences), which can occur when an incorrect pre-processing histogram is selected, e.g. an adult histogram for the radiography of a paediatric chest (Papp, 2006: 186). Since histogram errors result in images appearing with incorrect densities/brightness, it is important to assess if these errors had an impact on the chest (PA/AP and LAT) and abdominal (erect and supine) images that were assessed in this study.

Element 7: EI values

The Agfa CR reader system (which is used in both research sites of the study), uses EI values that are generated with each exposure. EI values fall into different categories depending on which anatomical part is being examined. The different acceptable AGFA EI values for chest and abdomen images in this specific study is as follow: Chest EI values are between minimal and maximum values of between 345 and 689, while abdomen images EI values are between minimum and maximum values of 172 and 344 (Adams, 2015: 5).

When considering the EI values, the assessors had to indicate large density differences as well as whether the collimation had been applied and if so, whether too much or too little had been applied. These factors are explained as follow:

- **Large density differences**
  These appear as dark bands at the interfaces of structures that differ widely in brightness level such as barium examinations or metal prosthesis (Papp, 2006; 188).

- **Too much or little collimation**
  Incorrect collimation or no collimation can lead to off-focus scatter in the histogram records of assessed chest and abdomen images in this study, as discussed in aforementioned Element 3. It can also lead to an incorrect EI number (Carlton & Adler, 2013: 350). Collimation is very important in reducing scatter radiation, improving image contrast and reducing the area irradiated.

Element 8: Image quality

In the research study, the qualitative elements in the data were measured using qualifiers on a scale of 1 (poor) to 5 (excellent). The qualifiers were used to grade the degree to which a particular quality was given in the images analysed (Rohrmann, 2007: 5).

The image presentation took the following factors into consideration:

- **Contrast**
  Papp (2006: 296) refers to *contrast* as the difference between optimal densities on a processed radiograph and functions to make detail(s) visible.

- **Density/brightness**
  The optimal density of images created by digital imaging systems is determined by the brightness level of the pixels in the image matrix (Papp, 2006: 296). A quality image has sufficient density/brightness to display anatomic structures.

- **Distortion**
  Distortion is a misrepresentation of the true size, shape or spatial relationship of an object in a radiographic image (Papp, 2006: 300). Papp lists the three types of distortion as:
    i. *Size distortion* is the result of the divergence of the x-ray beam from its source.
    ii. *Shape distortion* is caused by improper alignment of the part with respect to the x-ray source and image receptor.
    iii. *Spatial distortion* is the misrepresentation of the true spatial relationship among the various parts of the patient in the radiographic image (Papp, 2006: 300).

- **Scatter noise/fogging**
  Scatter noise is caused by the sensitivity of the IP to scattered radiation and is therefore susceptible to fogging (Drost, Reese & Hornof, 2008: 56).

- **Degree of sharpness**
  Sharpness is the amount of detail in an image by the spatial frequency resolution of the pixel layout (cf. 2.2.2.2) (Carter & Vealé, 2010: 228).

2.8 SUMMARY

This chapter discussed relevant literature on the topic under investigation, clarifying the image recording techniques used in the two hospitals that were evaluated. Firstly, the chapter provided a background of conventional film-screen radiography, comparing it to the CR used in this study. Secondly, it examined existing studies on the topic under scrutiny. The question that comes to mind is, why these specific image recording techniques? As clarified in the various studies on CR cited, it can be stated that the eight elements listed in section 2.7.2 play a vital role in the quality of radiographic images when working with a CR system. The literature reviewed therefore specify the different image recording techniques which should be considered.

Chapter 3, which follows presents a comprehensive view of the design and methodology utilised in the study.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

In the previous chapter, it was indicated at the hand of relevant literature that CR relies on the same image recording techniques as was the case with film-screen imaging. The studies cited in the literature review clarified how film-screen imaging and modern CR systems function. Furthermore, the chapter evaluated image recording techniques, highlighting principles of best practice to obtain optimal image quality when using CR systems (Pongnapang, 2005: online).

The objectives of this study were to identify the CR image-recording techniques used at private and government hospitals in the Eastern Cape province of South Africa and to evaluate these techniques to determine their influence on EI values. Chapter 3 outlines the methodology used to evaluate the image recording techniques in the production of chest (PA/AP and LAT) and abdominal (erect and supine) images. It discusses the theoretical orientation of the research design, the methodology and procedure, and data collection and analysis method.

3.2 THEORETICAL ORIENTATION OF THE RESEARCH DESIGN

The research design entails plans and procedures that determine a spectrum of decisions, ranging from broad assumptions to detailed methods of data collection and analysis. Creswell (2014: 247) notes that the research design involves a combination of philosophical assumptions, designs and specific methods. Retrospective design is a method employed to explore a situation using available data for the period of the study (Okeke & van Wyk, 2015: 167). In this study, a retrospective design was followed, in as much as the researcher selecting images retrospectively and analysing them according to the checklist. The participating departments and their radiographers were not informed beforehand of the proposed study, therefore it can be stated with certainty that their normal routines and attention to detail were not influenced. Image recording techniques were scrutinised, with particular focus on the definite EI values, which were observed with given exposure factors on the images being analysed.

Quantitative data with qualitative elements were collected. Quantitative research is used to quantify the problem by generating numerical data from raw data and transforming it into useable statistics. Quantitative research uses measurable data to formulate facts and uncover patterns in research (DeFranzo, 2011: online). According to Creswell (2014: 247), quantitative research allows for the testing of objective theories by examining the relationship among variables. It allows for the variables to be measured so that numerical data can be analysed by using statistical procedures. The qualitative elements included in this study were used to explore underlying reasons, opinions and motivations for the quantitative information provided. As described by DeFranzo (2011: online), qualitative research provides insight into the problem or helps to develop ideas for potential quantitative research. In this study, the general radiographic image recording techniques were assessed (cf. 2.7.1).

3.3 RESEARCH METHOD AND PROCEDURES

The research method involved the use of a checklist as the research tool. In the following section, the research tool is described and validated.

3.3.1 Research tool

A research tool is the means by which information is collected for a research study (Raqualia Pharma Inc., 2016: online). In this case, the research tool was a self-designed checklist (Appendix A) in which the key elements of image recording techniques were documented after image evaluation.

The design of the checklist was informed by the literature consulted in Chapter 2 (cf. 2.7.2). The identified techniques are applicable to most areas of radiographic imaging, therefore a pre-pilot study was conducted to identify the areas in radiographic imaging where EI values fell outside the acceptable range in the most commonly requested procedures. The pre-pilot study gave a clear direction of what image recording techniques the study should concentrate on and thus, formed part of the pilot study.

3.2.2 Pre-pilot study

As part of the pre-pilot study, the researcher performed exploratory observations on the NX workstation, viewing all radiographic images taken during a normal working week. The radiographic images were saved at the workstations for viewing before being deleted.

Chest (PA/AP and LAT) and abdominal (erect and supine) examinations were selected for the research study. These examinations were also deemed appropriate as they were the most commonly requested procedures by doctors in the surgical and medical departments of the two hospitals. The radiation dose to the organs in the chest and abdominal area is also crucial; these areas are close to the thyroid and the gonads and are therefore particularly vulnerable to radiation.

3.3.3 Pilot study

A pilot study (Appendix B) is used as part of the research design to check the sampling techniques. It is also used to test the validity and reliability of a research tool (Moule & Hek, 2011: 30). A pilot study was therefore conducted to validate the effectiveness of the tool and the value of the checklist in terms of answering the primary research question. The pilot study involved the evaluation of 20 images by the researcher and a quality assurance radiographer at a government hospital in the Eastern Cape province. The radiographer responsible for quality assurance and the researcher used the checklist to visually assess the CR image recording techniques and exposures used in the department before the study was conducted. All the images assessed for the pilot study were not from the research site but also from a different government hospital in the Eastern Cape province. For this reason, the evaluation of these images was not included in the actual sample of the research study. The results of the pilot study indicated that no changes were needed to the original checklist.

3.3.4 The study location and population

The study was conducted at two hospitals, one private and the other governmental, both in the Eastern Cape province on the southeast coast of South Africa. The radiology departments of these hospitals offer general x-ray examinations, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound (US) services. Fluoroscopy examinations are only provided at the government hospital.

A population is the total group of subjects that meets a designated set of criteria. De Vos, Strydom, Fouché and Delport (2005: 193) define a population as a set of elements that the research focuses upon and to which the obtained results should be generalised. The target population in this research study consisted of all the radiographic images taken at the private and government hospitals taking part in the research project. No individuals formed part of the population although qualified diagnostic radiographers were responsible for the production of the images collected for the study.

3.3.5 Study sample size and random sampling

A probability, unsystematic, simple random sampling method was used for the images collected. Simple random sampling was chosen because it is a method by which each individual in a population theoretically has an equal chance of being selected (De Vos *et al.,* 2005: 200). The unsystematic, simple, random sampling that was used was based on the 'lottery method'. According to this method, each member of the population is assigned a unique number. Each number is placed in a bowl or a hat and mixed thoroughly. The blind-folded researcher then picks numbered tags from the hat. All the individuals bearing the numbers picked by the researcher are the subjects for the study (Explorable, 2009: online).

In the random sampling method approach, every third entry of either the chest (PA/AP and LAT) examinations, or abdominal (erect and supine) examinations in the respective workbooks was selected. An interval of three was chosen based on the requirement to have both a random sample whilst also maintaining the probability of selecting the correct number of images every week (De Vos *et al.,* 2005: 226-228). A three-month period during which the selections were made was chosen, as staff work on a rotation basis and are not always present within the same section.

A simple random sample of 100 images per examination was selected for use in the study. The images consisted of the following projections: chest (PA/AP and LAT) and abdominal (erect and supine) images, resulting in a total of 400 images per hospital. However, the government hospital reverted to digital image production during the process, which reduced the amount of images per examination. As a result, the images were collected over two weeks only. This reduced the sample size to: chest PA/AP (n=80), chest LAT (n=80), abdomen erect (n=80) and abdomen supine (n=80), which resulted in 320 images in total for the government hospital. Therefore, each assessor assessed a total of 720 images, namely 400 from the private hospital and 320 from the government hospital.

3.3.6 Validity and reliability

In the evaluation of research designs, Abbott and McKinney (2013:45) point out that two issues are important to assess, namely validity and reliability. The type of validity and reliability used in this research was construct validity and retest reliability.

3.3.6.1 Validity

Validity is defined as the extent to which a research measure actually captures the meaning of the concept it is intended to measure (Abbott & McKinney, 2013: 81). Construct validity determines whether a measure of concept relates strongly to another measure that it should strongly correlate with (Abbott & McKinney, 2013: 82). Construct validity refers to whether the operational definition of a variable actually reflect the true theoretical meaning of a concept. (Shuttleworth, 2009: online).

In this study, validity was guaranteed by conducting a pilot study (Appendix B). The purpose of the pilot study was to verify the checklist. The image recording techniques identified through the pilot study evaluation model involved “trying it out on a small number of subjects having characteristics similar to those of the target group” (Singleton *et al.*, 1988: 290).

Validity was further enhanced as the checklist design was developed by consulting relevant literature (cf. 2.7.2). The current study is therefore also a point of reference for further research studies using the same research tool. In addition, the researcher also devoted time to a preparation stage completed with the assessors before the actual assessment period, in order to clarify how they should assess the radiographs, .This ensured that all assessors understood the checklist and used it in the same way. The preparation stage of assessing the checklist ensured greater statistical accuracy and prevention of bias.

3.3.6.2 Reliability

Reliability is the extent to which a research measure consistently evaluates a concept (Abbott & McKinney, 2013: 81). In this study, reliability refers to the consistency with which the three assessors treated all participants in the research, being the qualified diagnostic radiographers' images. Furthermore, it was ensured that the checklist evaluation items were free of measurement error, e.g. incorrectly worded items, etc. This means that if the same variable is measured under the same conditions, a reliable measurement procedure should produce identical, or nearly identical measurements (De Vos *et al*., 2005: 162). In other words, no fluctuation should occur unless there are variations in the variable that is being measured. However, one should bear in mind that there is always room for error in measurement (Moule & Hek, 2011: 103).

The reliability of this research was ensured through the pilot study, which tested the checklist before utilising it in the final research study. The content of the research tool was evaluated, discussed and amended prior to distribution to ensure reliability and validity. All information on the checklist was standardised since the information needed was automatically recorded within the digitiser CR system.

Reliability was also ensured insofar as the researcher thoroughly discussing all the requirements and details of the checklist with each assessor. The checklist also contained explanations for each category within the grading framework, which guided the researchers in reaching valid and reliable conclusions when evaluating the data (Agfa Healthcare NV, 2014; Carlton & Adler, 2013; Fauber, 2013; Papp, 2011; Seibert & Morin, 2011; Carter & Veale, 2010; CRCPD, 2008; Siegel & Kolodner, 1999).

Inter-rater reliability (IRR) was also tested with the appropriate statistical Cronbach's Alpha Test (Trochim, 2006: online). George and Mallery (2003) provided the following approach: if the Cronbach's alpha is above 0.9 = excellent, above 0.8 = good, above 0.7 = acceptable, above 0.6 = questionable, above 0.5 = poor and below 0.5 = unacceptable. Therefore, the reliability instrument in this study was that the Cronbach's alpha was 0.714, which indicates an acceptable standard of reliability. This IRR therefore assures that the assessments performed by the three assessors are valid.

Intraclass correlation (ICC) was also measured from the analysis of variance given by SPSS, being 0.621. The ICC is used to assess agreement when there are two or more independent matters and the outcome is measured at a continuous level (Heidel, 2018: online). According to Elizabeth DeLong, ICC ranges from completely correlated (ICC=1) to no correlation (ICC=0) (DeLong, 2017: online). This ICC therefore also assures that the assessments performed by the three assessors are valid.

3.3.7 Inclusion criteria of the images

The three reviewers were responsible for the assessment of the radiographic images of chest (PA/AP and LAT) and abdominal (erect and supine) images. All images of adults and children, both male and female, obtained from the x-ray department as well as other referred departments were included in this study. The images selected included ambulant and trolley patients. Only the images produced during the identified three-month period were selected for the study.

3.3.8 Exclusion criteria of the images

Except for the chest PA/AP, chest LAT, abdomen erect and abdomen supine images, all other images were excluded from the study. All images taken by students were also excluded from this research.

3.4 DATA COLLECTION

The following section elaborates on the data collection of this research study. Follow-on, three assessors assessed the images collected in the study and an explanation of the method of assessment is provided. The section also describes the two hospitals from which the data were collected in terms of how much data were captured over the three months.

A schematic outline of the data collection is presented in Figure 3.1.

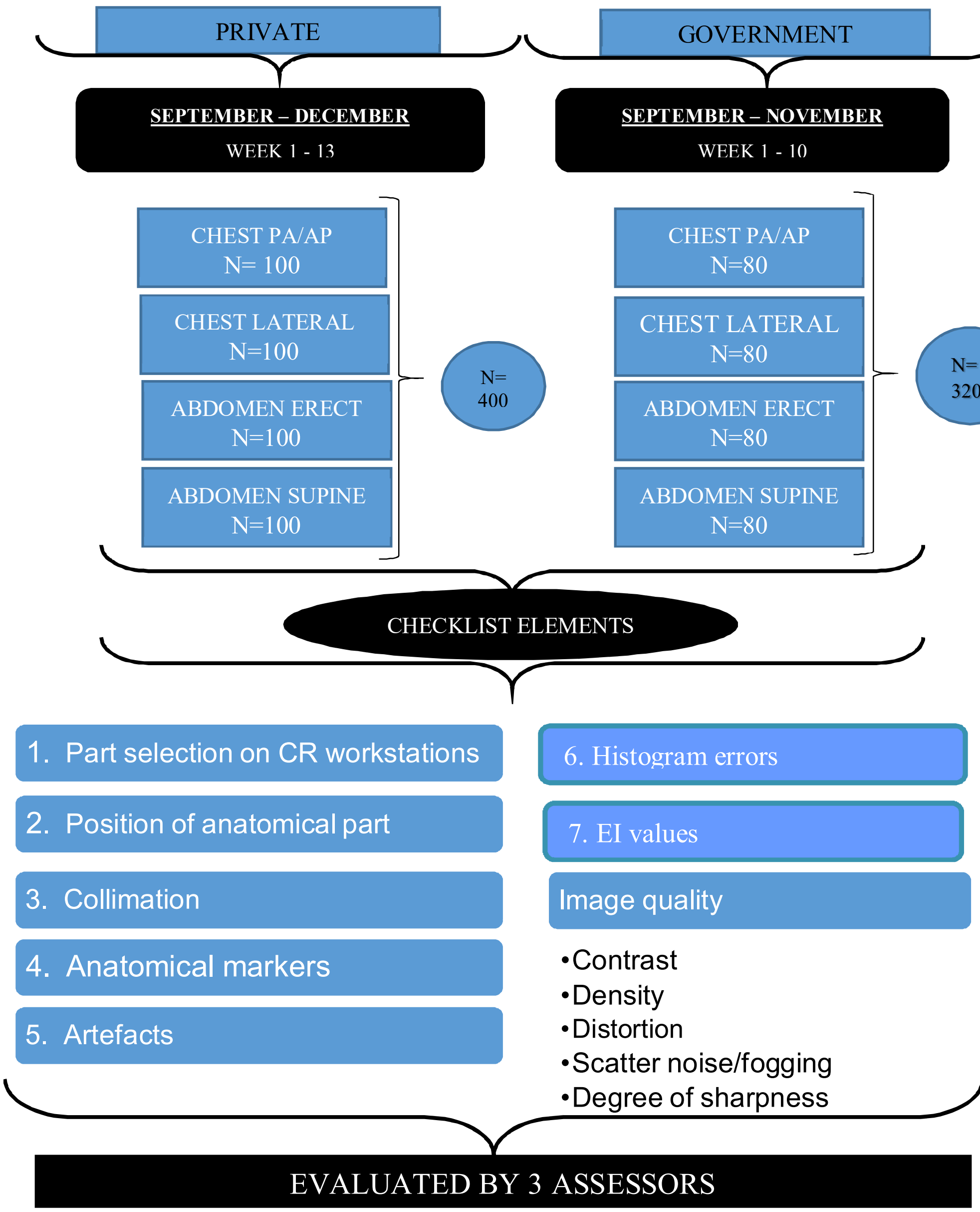


Figure 3.1: Schematic overview of data collection (Compiled by the researcher, Nel 2017).

3.4.1 Private hospital

The private hospital uses a radiology information system (RIS) to record the patients examined. User specific categories are available with RIS and were used to locate all the chest (PA/AP and LAT) and abdominal (erect and supine) images completed on the specific days that capturing needed to occur. Thereafter the chest and abdomen image data were searched for and displayed on a list that was acquired from RIS. The exclusion of student images was not necessary, since they were not 'in practice' at this specific private hospital at the time of data capturing. The RIS list of chest (PA/AP and

LAT) and abdominal (erect and supine) images attained, were then searched for on the NX workstation and recorded by the researcher. The researcher used a simple random sampling method of selecting eight (8) chest (PA/AP and LAT) and eight (8) abdomen (erect and supine) radiographic exposed images each week, in the order of selecting every third image given on the RIS list. The capturing was done through the function of the 'closed examinations' bracket with NX workstation. All diagnostic radiographers initialise the x-rays electronically, so there was no possibility of selecting a corrected image. No personal patient details were necessary and these were therefore not collected or used.

As explained in Chapter 2 (cf. 2.2.2.3), NX workstation allows diagnostic radiographers to use the quality assurance help tool to select images from the workstation, monitor dose variation on every exposure and analyse reject statistics. The NX workstation can view images in a 'closed examination' file by allowing the researcher to return the saved images to the original image taken. This function made it possible for the researcher to view the original images of every radiographer in the radiology department.

3.4.2 Government hospital

The government hospital on the other hand, has separate workbooks that are completed for every patient being x-rayed in the out-patient, in-patient, mobile and emergency departments. These workbooks contain the initials of the radiographer performing the x-ray, the patient's identity number, hospital number and type of examination requested by the doctor. These workbooks were therefore used as a guideline to randomly select which specific images to assess, intentionally to exclude any images obtained from students. NX workstations store the daily examinations electronically. The researcher selected the chest (PA/AP and LAT) and abdominal (erect and supine) images using a simple random sampling method. The simple random sampling method commenced on the first day of the starting date of the study. Once every week, at least eight images for that week were selected from the patient daily log book. The simple random sampling method made it possible for the researcher to select ten (10) chest (PA/AP and LAT) and ten (10) abdomen (erect and supine) radiographic exposed images each day, in the order of selecting every third image written in the workbooks.

All images captured from private and government hospitals were saved on compact discs that were distributed to the other two assessors. These two assessors were given a period of three months to complete their assessment of the images presented to them on the compact discs.

3.4.3 Assessors

The assessors responsible for the retrospective assessment of radiographic images consisted of the researcher, a clinical lecturer in radiography at a government hospital and a lecturer at a university in the Eastern Cape. The overriding criteria for selecting assessors for the study was to focus on individuals who were working with these image recording techniques on a daily basis whilst also lecturing. No form of remuneration was provided to the assessors and therefore the individuals participated voluntarily. These criteria would ensure that the assessors not only had the practical knowledge, but also the theoretical background to correctly analyse image quality in terms of the checklist criteria. The lecturers who participated in the study signed consent forms (see Appendix C to E), agreeing to participate in the study and confirming that personal information would remain confidential. Confidentiality, as it relates to the images collected in the sample, was an important factor in the reliability of the study. This is discussed further on in the study.

As mentioned previously (cf. 3.3.6.1), a preparation stage was conducted with the assessors before the assessment to clarify how each individual should assess the radiographs. The researcher visited the lecturers individually to explain the checklist. After the checklist was read and examined, the researcher enquired if the assessors had any further questions regarding its use when assessing the radiographs and addressed these if and when necessary.

After data collection, all images selected in the sample were pre-numbered in week sequence, for example: Week 1, image 1= 1(1), Image 2= 1(2), Week 2, image 1= 2(1) etc. This naming convention made it possible to refer to a specific image within the study. The team assessed a total of 720 images individually, which were copied from the CR workstations for each assessor. Each assessor viewed the images for assessment in an identical manner, with the help of the MicroDicom analysis tool, described in (cf. 3.4.4). The researcher collected the different images in the sample from the private and government hospital over a period of three months, where after the images were distributed on compact disc to the assessors for assessment.

3.4.4 MicroDicom analysis tool

MicroDicom is an application for the primary processing and preservation of medical images in DICOM (digital imaging and communications in medicine) format. The MicroDicom viewer application is equipped with the most common tools for manipulation while having an intuitive user interface (MicroDicom, 2015: online). This image reader (See Appendix F) was used to evaluate the DICOM images obtained by the researcher in their pre-processing format. The viewer does this by converting the DICOM images to common graphic formats such as jpeg, bmp, png, gif and tiff (MicroDicom, 2015: online). No patient information was available on the images assessed.

The MicroDicom programme is a free online programme which was installed for both assessors specifically for the purposes of the research. The programme was used by all assessors, ensuring the images were assessed consistently, in the same format

(See Appendix F). The evaluation details were confirmed on the hardcopy checklist so that each person assessed the images using similar viewing conditions.

All assessments of images were recorded on pre-printed, A4 hardcopy CR checklist pages provided by the researcher (See Appendix G). The hardcopy checklists were provided in four separate folders namely, a file for all the PA/AP chest images, a second file for all LAT chest images, a third file for all the supine abdominal images and a fourth file for all the erect abdominal images.

After the evaluations where concluded for the entire sample, the results of the hardcopy CR checklists were copied into tabular format in Microsoft Excel (see Appendix H) to enable the researcher and the statistician to perform the further statistical analysis, which is discussed in Chapter 4. The instructions from the statistician regarding the layout and structure of the Excel document to capture the data were adhered to, as demonstrated in Appendix H which is a sample of the feedback from the three assessors. The intent of Appendix (Appendix H) is to provide an overview of the results since providing the entire data set would be impractical due to the volume of information. The data were categorically captured by the researcher and analysed by the quality assurance radiographer to ensure accuracy before sending the hard and soft copies of the sample to the statistician. Thus, the data were also provided to the statistician to verify the accuracy of the checklist results copied to Excel, through the use of a data theme analyses technique, which is explained in the following section.

3.5 DATA ANALYSIS

The quantitative and qualitative elements on the checklist were assessed by three assessors. One of the assessors, the researcher, also undertook a qualitative analysis of the comments made by all three assessors in relation to the images.

The technique used to categorise qualitative data is referred to as ‘data theme analyses’, described by Ryan and Bernard (2003: 85-109). This describes the process of discovering themes within the data. Themes represent abstract, often ‘fuzzy’, constructs, which researchers identify before, during, and after data collection. The themes are identified by assessing the data collected. Various techniques can be used to discover these, which include (1) the analysis of words (word repetitions, key indigenous terms and key-words-in-context), (2) the careful reading of larger blocks of texts (comparing and contrasting, social science queries, and searching for missing information), (3) the intentional analysis of linguistic features (metaphors, transitions, connectors) and (4) the physical manipulation of texts (unmarked texts ‘and’ ‘cut’ and ‘sort’ procedures).

As explained by authors Ryan and Bernard (2003: 85-109), the technique which was used in the analysis was that of key-words-in-context. Key-word-in-context is based on a simple observation: to understand a concept, it is necessary to look at how it is used. In this technique, researchers identify key words and then systematically search the main body of text to find all instances of the word. The qualitative data analysed in this study were categorised according to themes, being the key-words-in-context, which were identified through observation of the comments. The actual comments are much wider in some instances and highly inconsistent in terms of the structure of wording used, hence the need for the identification of themes. The themes were informed by key words or concepts, which recurred throughout the qualitative data. The reason for this secondary revision was to ensure statistical accuracy and to eliminate bias. The researcher also informed the statistician of the specific themes that had to be focussed on during the data analysis process using SAS Version 9.2. Various applicable qualitative themes (see Appendix I for the subdivision of 'category' and 'key words/themes') were identified through the use of this method.

The data of each assessors' input were then combined per quantitative and qualitative elements respectively. The median and statistical average were determined per category. The assessors' input was combined to ensure that there would be no bias however, as indicated in Chapter 5, this is also a limitation of the study as more assessors assessing the same images would produce statistically more accurate results. The study does not statistically exclude the dissenting view on a particular observation due to the reliance on averages. Therefore, this equal weighting of inputs ensures the reliability of the study.

However, the reliability of the results was ensured as the researcher combined descriptive data, namely frequencies and percentages. Means and percentiles were calculated from the numerical data obtained. Furthermore, data were analysed as being reliable through IRR whereby the Cronbach's Alpha was calculated. The interrater reliability demonstrated that the statistics are reliable.

3.5.1 Verification of the data input

Numerical data were captured by the researcher onto an Excel spreadsheet in accordance with instructions from the statistician who double-checked it to ensure accuracy. The verification and accuracy of the data input was cross-checked by the radiographer responsible for quality assurance at the government hospital to ensure that all the data input was correct.

3.6 ETHICS

Ethical issues need to be considered in all research studies. This is in order to protect the research participants, to develop mutual trust, promote the integrity of the research and guard against any misconduct or impropriety that may bring the researcher's institution into disrepute (Creswell, 2014:92). The ethical considerations were addressed by obtaining permission and ethical approval to conduct the study, as discussed in the following section.

3.6.1 Permission

Permission to execute the study was obtained from the Faculty of Health and Environmental Sciences Evaluation Committee at the CUT (see Appendix J). Permission to perform the study was also requested from the chief radiologist of the private hospital and the chief executive officer (CEO) of the government hospital (see Appendices J and K). The chief radiologist and the CEO, who are ultimately responsible for all activities taking place in the hospital, authorised the heads of the radiology departments to allow the study to proceed. The letter (see Appendix K and L) requesting permission contains the title of the research as well as a brief explanation of the benefits of the study, which would assist the hospitals in improving the diagnostic images produced by the diagnostic radiographers. The heads of the radiology departments were also informed of the procedures of the study, its duration as well as the confidentiality agreements signed by the assessors.

3.6.2 Ethical approval

No patient information was accessed during the study and no experimentation on live subjects or tissue samples was carried out. Approval to conduct the research project was obtained from the Health Science Research Ethics Committee of the Faculty of Health Sciences (UFS) under ECUFS Number 197/2015 [see Appendix M]. All personal information was kept confidential.

3.7 SUMMARY

This chapter described the research design and methodology of the study. The chapter began with background information on the study, outlining the theoretical orientation of the research design and the quantitative research design methods considered, namely the checklist. This was followed by an explanation of the data collection process and included the analysis techniques used by the researcher prior to handing over the data to the statistician. In Chapter 4, the results of the study are presented, analysed, interpreted and discussed, using tables and figures to illustrate the findings.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In Chapter 3 (cf. 3.3) the checklist as part of the research method used in this study was presented. The three assessors used the checklist to assess the quantitative and qualitative elements. The results obtained from the checklist will henceforth be discussed in this chapter, with the aim to present the research findings in response to the research questions of this study.

The results were analysed, interpreted and will be discussed in the sections to follow. The results will be presented in graphs and tables with further sections discussing the analysis and clarification of the presented results. The discussion of results enabled the formulation of conclusions and recommendations made in Chapter 5.

4.2 ANALYSIS, INTERPRETATION AND DISCUSSION OF THE RESULTS

Section 4.2 provides a description of the demographic population, a summary of the different components of the checklist assessed by three assessors. The results are presented as follow:

- The description of the sample population (cf. 4.2.1).
- The image recording techniques data of chest (PA/AP and LAT) and abdominal (erect and supine), including the analysis of three different assessors (cf. 4.3).
- The assessment of the image quality (cf. 4.4).

4.2.1 Description of the sample

A probability, unsystematic, simple random sampling selection was used in this study. The sample at a private and government hospital was as follow:

4.2.1.1 <u>Private</u>

One hundred images (n=100) per examination created at the private hospital were included in the study. The images consisted of the following projections: CXR AP (n=100), CXR LAT (n=100), AXR Erect (n=100) and AXR Supine (n=100), resulting in 400 images (n=400) in total.

4.2.1.2 <u>Government</u>

At the government facility 80 images (n=80) per examination were included in the study. The images consisted of the following projections: CXR AP (n=80), CXR LAT (n=80), AXR Erect (n=80) and AXR Supine (n=80) resulting in 320 images (n=320) in total.

As seen from the aforementioned, the private hospital had a larger sample compared to the government hospital. The number of images sampled from both hospitals combined was 720 (n=720) in total, which each evaluator assessed independently.

4.2.2 Data capturing at the hospitals

The data was captured at the private hospital over a period of 13 weeks, whereas at the government hospital the process took 10 weeks. The private hospital had a collection of eight images per examination for 12 weeks and four images in the 13th week. The government hospital, on the other hand, had a collection of eight images for 10 weeks.

4.3 IMAGE RECORDING TECHNIQUES

This section presents data on the image recording techniques of the images included in the study and assessed by the three assessors. Firstly, the results of the PA/AP and LAT chest images will be presented followed by the erect and supine images of the abdomen.

4.3.1 Part selection on CR workstations

The assessors indicated that an average of 97% of PA/AP chest images were selected correctly on the CR workstation whereas 96% of LAT chest images were correctly selected. A total of 95% erect abdominal images and 96% supine abdominal images were correctly selected. Conversely, only 5% erect and 4% supine abdominal images were incorrectly selected. This resulted in the majority of CXR images being correctly selected.

As emphasised by Carter and Vealé (cf. 2.3.3.1), part selection has an important influence on the EI that is calculated digitally by the computer system. The high percentages (96% and 97%) of chest images in this study indicate that nearly all the chest images on the CR workstations included in the study were selected correctly. According to the data analysis, presented as the averages of 95% erect and 96% supine abdominal images, the selection of the correct processing algorithm was also at a consistently high level of accuracy. These results indicate that the staff members at the two hospitals in the study were able to select the correct algorithm when performing chest and abdominal examinations.

The results also indicated that less histogram errors occurred in relation to the selection of incorrect part, which resulted in less artefacts on the chest images (cf. 2.3.2). Choosing the correct algorithm also determined if the correct reference EI for the anatomical part was used. EI is the only way by which a diagnostic radiographer can determine if the correct exposure factors were used during an examination.

It was noted that nearly all the erect and supine abdominal images on the CR workstations were selected correctly on the CR computer. These results are comparable to the results from the chest image observations insofar as the percentage of incorrect body part selected does not differ. Therefore, these results indicate consistency of the correct part selection across all projections that formed part of this study.

4.3.2 Positioning of anatomical parts

The total of correctly positioned anatomical parts to the collimated area of PA/AP chest images was 65% and 53% for LAT chest images (see Appendix O). Of the total abdominal images assessed for both positions, the average of 58% erect abdominal and 59% supine abdominal images were correctly positioned in the collimated [see Appendix O] area according to all three assessors.

Looking at the results of the incorrectly positioned chest and abdominal images, it highlighted the fact that this had led to poor image quality (cf. 2.3.3). The results therefore indicate that an unacceptably high number of chest examinations that is 40.83%, had non-optimal positioning, which is ultimately the sole responsibility of a diagnostic radiographer.

As indicated in the technical assessment of chest and abdominal radiographs (see Appendix N and O), positioning plays a vital role in producing an acceptable diagnostic abdominal image. It stands to reason that when the anatomical part is not correctly positioned, an undesirable result of non-optimal image quality will be obtained. Firstly, no anatomical part is cut off during examination positioning. Secondly, geometric factors such as the non-optimal image sharpness of the abdominal images and distortion will occur. A total of 42% erect and 40% supine abdominal images was incorrectly centred. These percentages (42% and 40%) indicate a consideration for optimisation.

4.3.3 Collimation

Collimation was evaluated according to the Bontrager and Lampignano (2014: 84,112) guideline where chest boundaries include the outer skin margins on each side of the chest surface when lungs expand during deep inspiration. Abdomen on the other hand has two projections included in this specific study (erect and supine), which differ (see Appendix O). The results showed that no collimation was applied in an average of 67% PA/AP chest, 61% LAT chest 74% erect and 69% supine abdominal images.

As a result, optimal collimation was not applied in most of PA/AP and LAT chest images. Thus, it can be assumed that radiographers rather used non-optimal collimation to make sure that they do not 'cut' off any part of the chest anatomy when exposing during suspended inspiration (Appendix N). No collimation averages also resulted in 26% erect and 31% supine abdominal images, as assessed by the three assessors.

As indicated in Chapter 2, in Element 3 (cf. 2.8.2), IAEA (2011) it specifies that proper collimation plays a vital role in CR software to establish the correct EI value. Furthermore, collimation is a form of radiation protection and its proper application ensures that patients have been appropriately protected (cf. 2.8.2).

IPs are sensitive to scatter radiation and primary beam collimation is of the utmost importance (cf. 2.8.2). The high average percentages of 67% PA/AP chest, 61% LAT chest, 74% erect and 69% supine abdominal image results of insufficient collimation applied, may confirm a negative influence of lowered image quality.

One of the uses of CR is that collimation can be applied after processing. Collimating after processing does not reduce the negative effects of scatter radiation and is therefore not a viable solution to incorrect collimation. Collimation not only results in optimal density and contrast for radiographic images, but also plays a vital role in radiation protection (cf. 2.4.1).

4.3.4 Anatomical markers

The results indicated that, on average, 48% of PA/AP chest images had no personal anatomical markers on the image. On average, 98% of the LAT chest images had no personal anatomical markers present. Of the abdominal images, 62% erect and 55% supine had no personal anatomical markers present.

As explained by Bontrager and Lampignano (2014) (cf. 2.8.2), for legal purposes 'right' and 'left' anatomical markers should be placed correctly before exposure for the permanent indication of an anatomical part. It should be noted that at both hospitals, the application of anatomical markers is not a requirement for LAT chest images as per the respective protocols. Nonetheless, a total of 2% LAT chest images were annotated with an anatomical marker.

The ability to use annotated left of right markers during post-processing may result in diagnostic radiographers not using their own personal positioning markers. One of the requirements of correct marking (cf. 2.5), which is recognised as a disadvantage of CR, stipulates that side or position markers should always be used, regardless of the opportunity to add the markers post exposure. It is therefore concerning to note that an average of only 38% erect and 44% supine abdominal images in the study were legally acceptable. Identifying the required anatomy on abdominal radiographs before processing is very important as it avoids the need to guess 'which side is which' when using the benefits of post-processing.

4.3.5 Artefacts

The following results present the incidence of different artefacts namely, gridlines, IP artefacts, foreign objects, plate reader, CR scanner malfunction and quantum mottle created during the imaging process. The results recorded are from all three assessors and for both hospitals combined.

4.3.5.1 Gridlines

According to the results of the PA/AP chest and LAT chest images, the three assessors indicated that there were gridlines present on an average of 2% of both PA/AP chest images and LAT chest images. The presence of gridlines on these images taken by diagnostic radiographers was the result of incorrect grid selection.

The abdominal images yielded an overall positive result, with only one (supine abdomen) image (0.2%) showing gridline artefacts. This is a remarkable result, with an average of 99.8% of all erect abdominal and supine abdominal images showing no gridline artefacts.

As mentioned by Pongnapang (2006: 3), some unwanted artefacts cannot be corrected by any image processing algorithm and care should be taken by the diagnostic radiographer responsible for the images in examinations. The average of 2% of chest images (PA/AP and LAT) taken by diagnostic radiographers that presented with gridlines was due to a mechanical fault or incorrect grid selection, whereas an average of only one (equating to 0.01%) incidence of gridline artefacts occurred on the erect abdominal images.

4.3.5.2 Image plate artefacts

The following Figures 4.1 and 4.2 depict the responses for PA/AP chest and LAT chest and supine and erect abdominal images to the question: ‘Are there any IP artefacts on the images of the study, and if so, should these be categorised as cracks, scratches or scuff marks?’

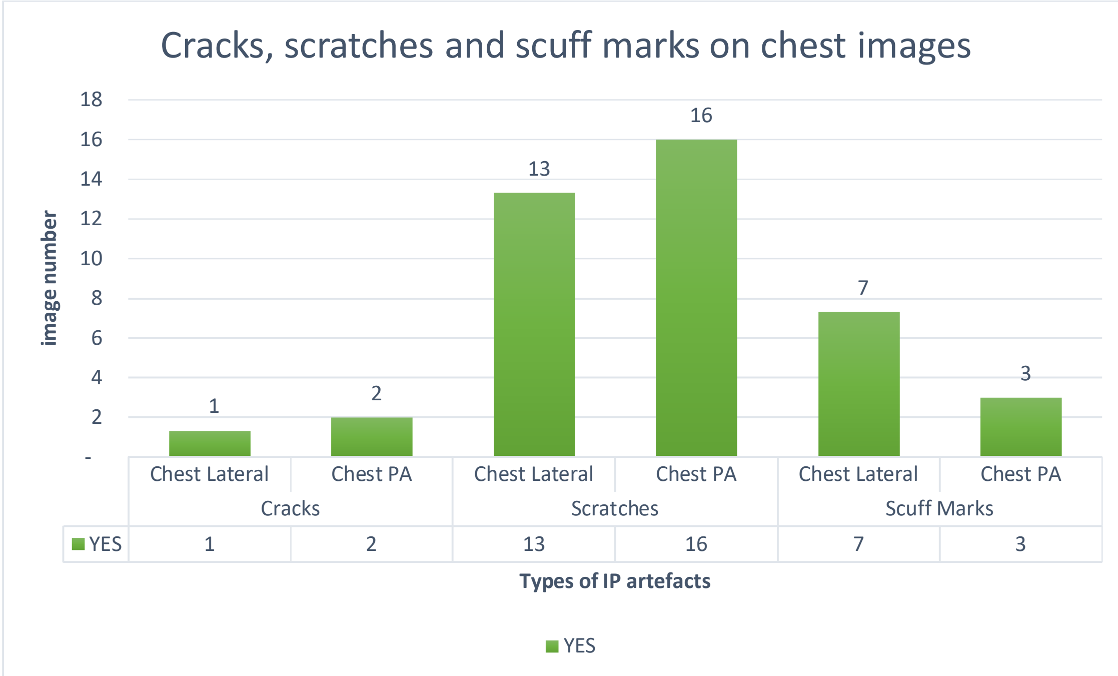


Figure 4.1 Type of IP artefacts on the PA/AP chest and LAT chest images.

Figures 4.1 and 4.2 illustrate the division of total images, with PA/AP, LAT chest, erect and supine abdominal images, demonstrating that the majority of IP artefacts occurring in all projections, were scratches. Accordingly, it is evident that scratches occurred in 16 (9%) PA/AP and 13 LAT chest images (7%) respectively. Additionally, scuff marks on LAT chest images also occurred in 4% (n=7) of the total. Scratches are a permanent artefact on the IP, and since the same IP is used repeatedly and for different examinations it is to be expected that abdominal images will comparatively have the same results as chest examinations.

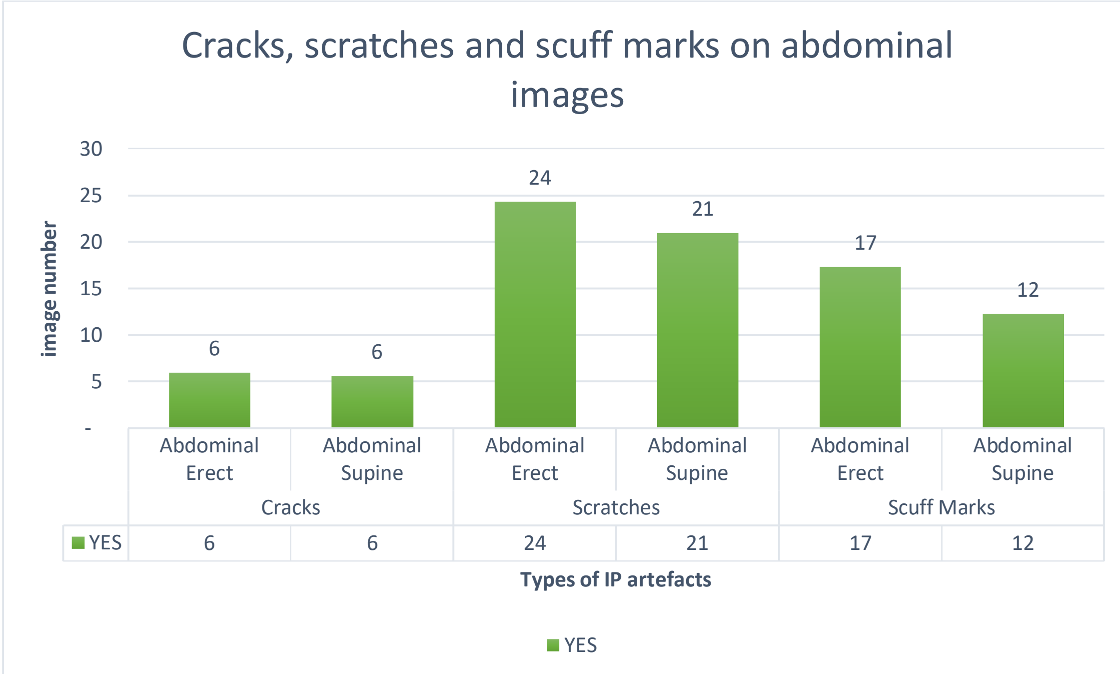


Figure 4.2: Type of IP artefacts on erect and supine abdominal images.

It is evident from Figure 4.2 that scratches on abdominal images, relating to 24 (14%) erect and 21 (12%) supine, were more dominant than other IP artefacts. Figure 4.2 also indicates that scuff marks on an average of 8% [n=29(17+12)] of abdominal images were substantially more frequent than the average of 3% [n=10(3+7)] of chest images.

As stated earlier in the literature review (cf. 2.8.2), every cassette containing IPs, has the possibility of having cracks, scratches or scuff mark artefacts, since negligence is one of the primary causes of these artefacts, mentioned by Shetty, *et al*.(2011: 39). Even though IP artefacts can be attributed to scratches and cracks (due to ageing, wear and tear, and roller-induced artefacts) the cassettes containing damaged IP should consequently not be used if these artefacts are visible. Based on the average of 8% [n=29(13+16)] on both chest image projections, and 13% [n=45(24+21)] on both abdomen image projections, it can be reasoned that a lack of maintenance is a factor and that the IPs should be checked and be replaced more regularly.

4.3.5.3 Foreign objects

There are a few factors that can affect the occurrence of foreign objects as artefacts. This study only focussed on three factors namely, dirt on the IP, objects not removed from patients and debris. Figure 4.3 illustrates foreign object artefacts categorised as dirt, objects on the patients or debris. The averages of foreign object artefacts on chest PA/AP images was 26% [n=56(21+25+10)] while for LAT chest images it was 26% [n=49(14+35+0)].

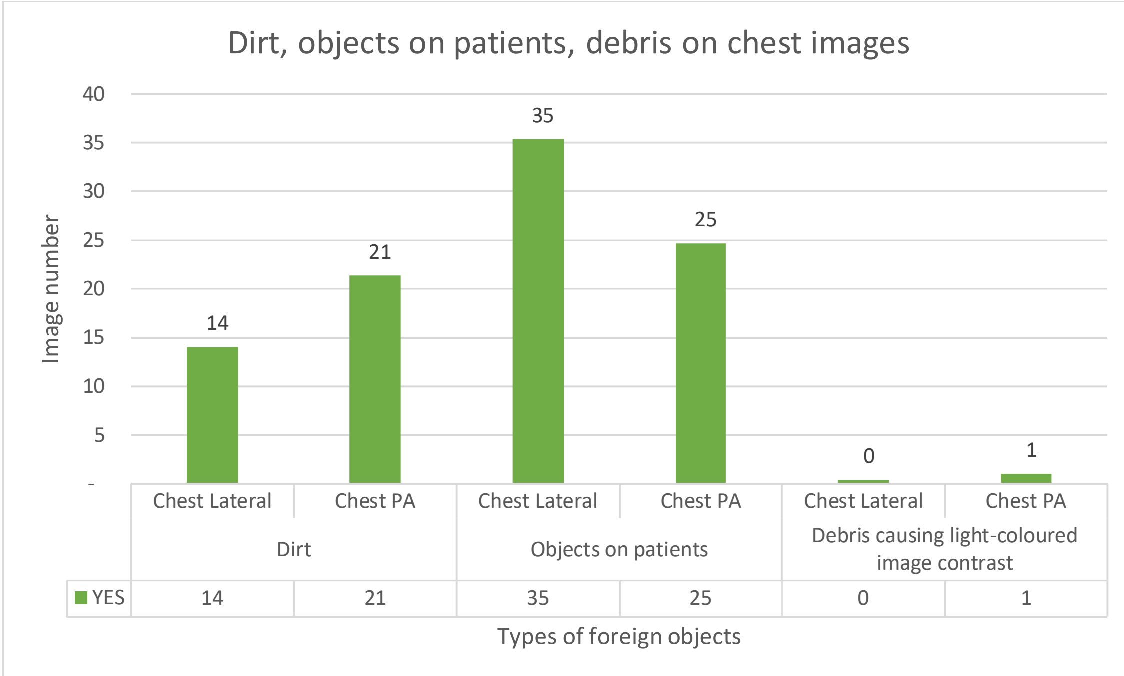


Figure 4.3 Type of foreign objects on the PA/AP chest and LAT chest images,

Figure 4.3 illustrates the division of total images. ‘Objects on patients’ occurred the most frequently with PA/AP chest images presenting with 14% (n=25) and LAT chest images presenting with 20% (n=35) in total. There was a low prevalence of debris on both chest images, with PA/AP chest being 0.6% (n=1) and nil LAT chest images, which is a good indication that cassettes are stored and handled with care.

The frequency of foreign objects in erect abdominal images averaged at 26% [n=69(28+41+0)] and 23% [n=42(19+23+0)] in supine images. The following Figure 4.4 demonstrates the division of overall abdominal images, with an average of 23% (n=41) of erect abdominal images and 13% (n=23) of supine abdominal images, showing that objects on patients are the most frequently occurring foreign object.

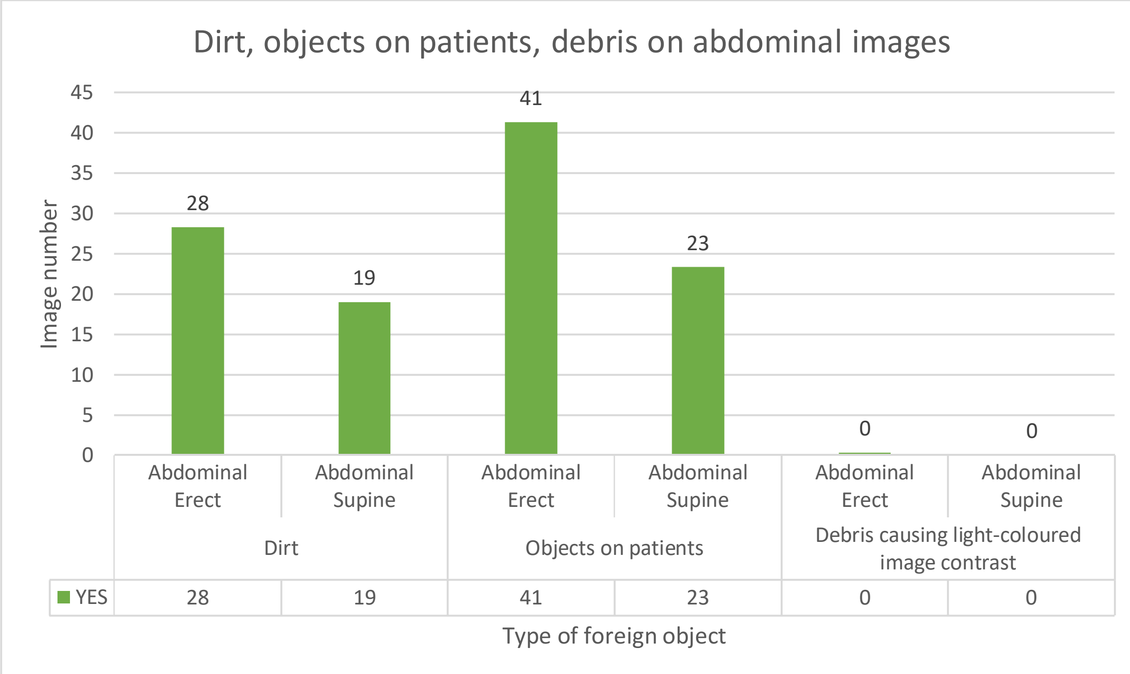


Figure 4.4 Type of foreign objects on erect and supine abdominal images.

Frequent opening and closing of the IP can increase dirt and dust contamination. This can cause radiopaque lines that can be traced on the images, since the dirt and dust are deposited on the IP while it passes through the rollers (Shetty et al. 2011: 40). Bearing in mind that the lungs in the chest consist of soft tissue, radiopaque lines can cover the soft lung tissue area, which can lead to a misdiagnosis such as heamothorax or pneumothorax, to name but a few. Another example is that calcifications or kidney stones can be falsely diagnosed when dirt on rollers mimics a foreign body (Yung, 2011: 72).

Dirt occurred on an average of 13% [n=47 of 360 (180 +180)] of both erect and supine abdominal images, as assessed by the assessors. It is therefore important to keep the abdomen (or any body part, for that matter) free of artefacts.

The results revealed that an average of 17% of chest and 18% of abdominal images contained artefacts due to ‘objects not removed from patients’. Removable artefacts include clothing, jewellery, fabric folds, hair or other objects, which could easily have been prevented from showing up in the radiographic image (Enfinger, 2015: 41). Non-removable artefacts include lines and tubes that are visible on the chest images however, these should never be manipulated or removed (Enfinger, 2015: 43). Mechanical artefacts, on the other hand, refer to equipment problems, technologist error or artefacts caused by errors (mentioned previously e.g. gridlines, scratches or dirt on IP) (Enfinger, 2015: 44).

Foreign objects in the abdominal images included removable artefacts such as jewellery, fabric folds, clothing and underwear. Radiographers should pay closer attention to verify that foreign objects have been removed from the patients before the examination takes place. Patients need to be undressed and wear hospital gowns prior to being examined, so that no foreign objects will appear on the images. Debris, on the other hand, is due to the improper handling of cassettes. There was no occurrence of debris artefacts in the chest and abdominal images, which averaged to nil respectively.

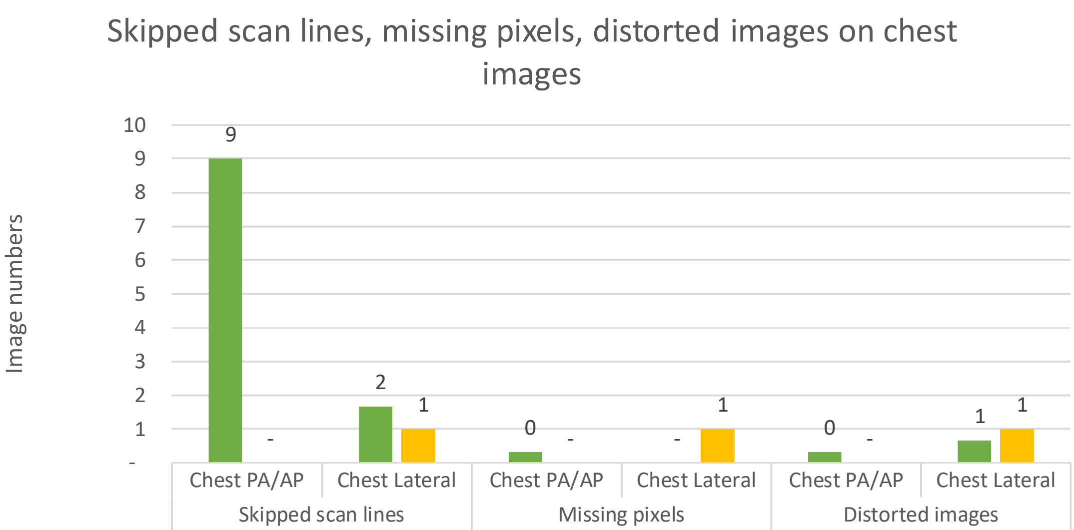
4.3.5.4 Plate reader

Most of the plate reader artefacts displayed extraneous lines. Such lines occurred on 18% (n=33) of PA/AP chest images and on 16% (n=29) of LAT chest images. Plate reader artefacts on erect abdominal images occurred on 26% (n=46) of images and on 21% (n=37) of supine abdominal images. Extraneous line patterns that occurred from this total were only averaged to 24% (n=43) for erect and 20% (n=36) for supine abdominal images.

Extraneous lines occurring in chest images presented at an average of 17% [n= 62 (33+29)] and an average of, 22% [n=79 (43+36)] in abdominal images. This result is significant since this artefact could have been easily avoided. Shetty et al. (2011: 40) stress that it is the responsibility of the quality assurance (QA) protocol of the radiology department to periodically clean the light guide and beam deflector, which can contain dirt or dust spectacles. Plate reader artefacts that cause extraneous line patterns are indubitably caused by dirt over the light guide, as explained in section 2.8.2.

4.3.5.5 CR Scanner malfunction

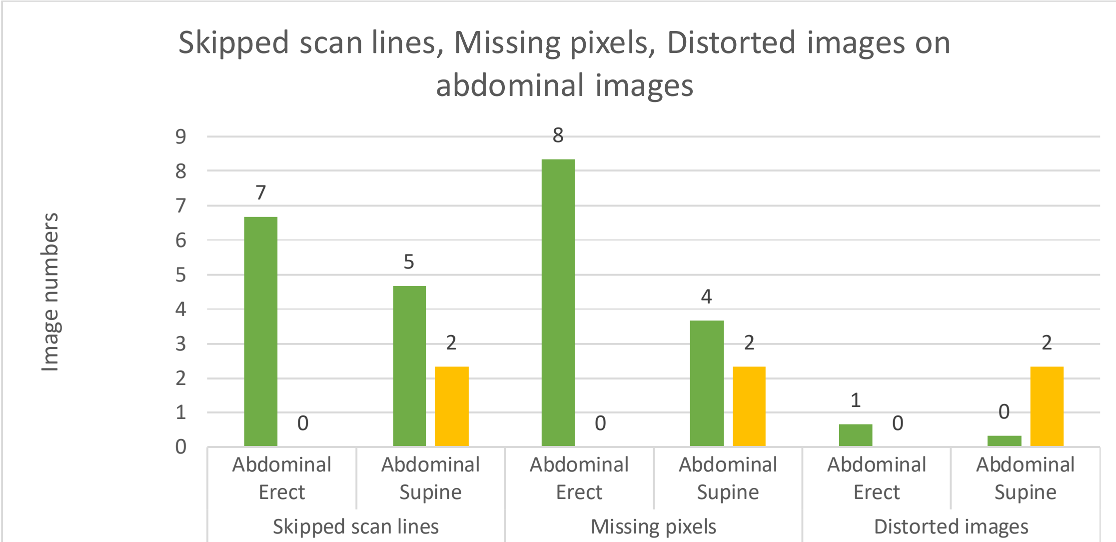
As illustrated in Figure 4.5 that follows, the total CR scanner malfunction artefacts regarding skipped scan lines of PA/AP chest images, presented at an average of 5% (n=9) and LAT chest 1.1% (n=2).



	Skipped scan lines: Chest PA/AP	Skipped scan lines: Chest Lateral	Missing pixels: Chest PA/AP	Missing pixels: Chest Lateral	Distorted images: Chest PA/AP	Distorted images: Chest Lateral
YES	9	2	0	-	0	1
NOT FILLED IN	-	1	-	1	-	1

Figure 4.5 Type of CR scanner malfunction artefacts on the PA/AP and LAT chest images.

Figure 4.5 illustrates the division of total chest images, with PA/AP chest displaying skipped scan lines as the most noticeable artefact in 5% (n=9) of the images. CR scanner malfunction artefacts of the abdomen is illustrated in Figure 4.6. As presented in Figure 4.6, scanner malfunction artefacts presented on average in 9% [n=16(7+8+1)] of erect and 5% [n=9(5+4+0)] of supine abdominal images.



	Skipped scan lines: Abdominal Erect	Skipped scan lines: Abdominal Supine	Missing pixels: Abdominal Erect	Missing pixels: Abdominal Supine	Distorted images: Abdominal Erect	Distorted images: Abdominal Supine
YES	7	5	8	4	1	0
NOT FILLED IN	0	2	0	2	0	2

Figure 4.6 Type of CR scanner malfunction artefacts on erect and supine abdominal images.

The most significant results were skipped scan lines and missing pixels, shown in the erect abdominal images, being an average of 4% (n=7) and 4% (n=8) respectively.

Constant motion of CR scanner rollers can cause malfunction. In the assessment of chest images in both hospitals, skipped scan lines accounted for the most frequent malfunction at an average of 3% [n=11(9+2)]. This artefact is caused by the slipping of rollers feeding the images through the processor. It is important to avoid this unnecessary artefact as it can lead to the misdiagnosis of patients. In the assessment of abdominal images, skipped scan lines occurred on average in of 3% (n=12) of images and missing pixels on average in 3% (n=11) of images. This was the highest incidence of malfunctions that occurred.

4.3.5.6 Quantum mottle artefacts

The blotchy appearance on the images known as ‘quantum mottle’, appeared more frequently on the LAT chest images than on the PA/AP chest images. The averages were 22% (n=40) for LAT chest and 5% (n=9) for PA/AP chest images. The responses received for erect abdominal and supine abdominal indicate that erect and supine abdominal images had more or less the same averages, namely 8% (n=14) to 7% (n=13).

As stated in Chapter 2 (cf. 2.8.1), overexposure is not beneficial to the patients under examination due to the risk of higher radiation. However, using a lower exposure than necessary for producing the image is also not beneficial to the patient, since quantum mottle necessitates a repeat. According to the study results, LAT chest images had a

17% greater average than the PA/AP chest results. It can be deduced that the reason for this is an incorrect exposure, meaning too little mAs were used, considering that the dimension of the LAT chest is a lot greater than a PA/AP view. In the following section, the EI values of the images assessed will specify if lower exposure (underexposed images) influences the quantum mottle occurring in the chest and abdominal images.

An increase in the mAs will minimise quantum mottle and thereby improve image quality. According to the responses received from the assessors, an average of 8% (n=27) of the total abdominal images showed signs of quantum mottle. Although CR has a wide exposure latitude advantage, this can result in a means for 'too little' or 'too much' exposure given to the patient during an examination. Quantum mottle on radiographic images can unfortunately not be rectified through post-processing. The reason for this being that when the number of final-state photons is received with exposure, it is potentially low and therefore the image will appear grainy and blotchy.

4.3.6 EI values

Table 4.1 below illustrates the responses received for PA/AP chest (n=180) and LAT chest (n=180) images to the question 'What is the comparison of EI values on the PA/AP and LAT chest images resulting in overexposed, underexposed, within range (or not filled in)?'

Table 4.1 Comparison of EI values on the PA/AP chest and LAT chest images.

	PA/AP chest	Percentage (%)	LAT chest	Percentage (%)
Overexposure	26	14%	27	15%
Underexposure	76	42%	81	45%
Within range	77	43%	71	40%
Not filled in	1	1%	1	1%
Total	**180**	**100%**	**180**	**100%**

As seen in Table 4.1, PA/AP chest images were mostly in range whereas 42% (n=76) of the images were underexposed. A total of 45% (n=81) LAT chest images were underexposed, whereas 40% (n=71) were in range.

The overall count of overexposed, underexposed and within range abdominal images is shown in Table 4.2. Averages of erect and supine abdominal images presented overexposure of 51% (n=93) and 52% (n=94) respectively, as the most significant in the results. Of the erect abdominal images, 30% (n=54) and of the supine abdominal images, 35% (n=64) were within range.

Table 4.2 EI values for erect and supine abdominal images.

	Erect Abdomen	Percentage (%)	Supine Abdomen	Percentage (%)
Overexposure	93	51%	94	52%
Underexposure	33	18%	20	11%
Within range	54	30%	64	35%
Not filled in	0	-	2	1%
Total	**180**	**100%**	**180**	**100%**

EI is linearly proportional to detector exposure (Seibert & Morin, 2011: 577) and does not reflect the radiation dose to the patient (cf. 2.3.3). It indicates to the diagnostic radiographer whether the correct exposure was selected for the projection to fall into the specific exposure range. It is noticeable that overexposure was only 15% for both PA/AP and LAT chest images compared to 51% for the erect and 52% for the supine abdominal images. The abdominal overexposure results in this study are concurrent with the literature (cf. 2.3.3), which indicates that CR can result in an increase in radiation dose to the patients. It is assumed that the most probable reason for this increase in dose is due to diagnostic radiographers' awareness that an overexposed image can be resolved with post-processing techniques. Diagnostic radiographers also need to avoid the occurrence of underexposure, which causes quantum mottle and can lead to the use of overexposure. These increases in exposure can lead to exposure creep (cf. 2.3.3).

The most surprising aspect of the data is that for PA/AP chest and LAT chest images, the overexposure, underexposure and within range retrospectively compared to each other were nearly similar in total. The overall underexposure of chest images (44% [n=157 (76+81)] indicates that less radiation was given to the patients. It also explains the average percentage of 15% (22% for PA/AP and 5% for LAT chest images) of quantum mottle, which occurred in the artefact section (cf. 4.3.5.6) of chest images, due to low exposures being used. Collimation also has a significant effect on the EI value result and should be considered if EI values were calculated correctly.

Conversely, the abdominal images only showed underexposure at an average of 15% (18% for erect and 11% for supine abdominal images). It is noticeable that overexposure occurred in 52% for the abdominal images compared to 44% underexposure for chest images. It can therefore be questioned if exposure charts are being used at both practices, since they are available, and if the patients are being measured? Underexposure in the abdomen would have been a more optimistic result since it is the anatomical area in which the gonads are located.

Noted from the results, an average of 41% of all the chest images were within range (43% of PA/AP chest and 40% of LAT chest), meaning that more than half the images were not exposed adequately to correspond to expected EI results. According to the average results, 33% [118 of 360 (180 + 180)] of abdominal images fell within the EI values expected. Thirty three percent of the abdominal images assessed represented the correct pixels in the image, displaying the correct anatomy and pathology for the radiologist to report on. This 'within range' only applied to approximately a third of the images, which is not a satisfactory result. As discussed previously (cf. 4.3.3), a large portion of chest and abdominal images were not properly collimated, which therefore influenced the percentage of correct EI values used, as observed in this study. Also mentioned was the fact that the patient size and the amount of mAs used, are directly proportional to EI value.

4.3.7 Histogram errors

A histogram is a graphical representation of pixel values. It is generated from the image data that allows the CR system to find the useful signal by locating the minimum and maximum signal within the anatomical region of interest in the image. LAT chest images had a higher number of histogram errors than chest PA/AP images, expressed as LAT chest 7% (n=35) to PA/AP chest 5% (n=26). Erect and supine abdominal images had equivalent average histogram errors of 3% (n=16) each. As revealed, very few histogram errors occurred in the abdominal images assessed by the three assessors.

As explained by Christensen, Jurkiewicz and Kawamura (2015) (cf. 2.8.2), histograms are formed when the laser reads the entire CR plate. This laser identifies collimation fields and whether the part under examination is correctly centred. As indicated in the discussion of histograms in Chapter 2 (cf. 2.3.2), it is important for the CR scanner to distinguish the useful region of the image by collimation field detection. As indicated with the results provided, histogram errors occurred in chest and abdominal images as a result of incorrect collimation, incorrect centring or other body parts appearing in the images. The images will be either underexposed or overexposed (known as 'rescaling errors').

Histograms are also directly linked to the part selection on the CR. According to the results of the study, an average of 6% of chest and 3% of the abdominal images had histogram errors. The results related to the factors that influence histogram errors seem to corroborate the histogram error results as part selection errors on chest and abdominal images both came to an average total of 4%. All the assessors also indicated that contrast was also affected by histogram errors. All three assessors indicated that most chest images included more than 50% of the abdomen while others showed 'metal hardware, breast implants, gonad shields, pacemakers or unwanted body parts' (such as pathology masses, etc.). All these factors had and influence on the histogram percentages. The comments made by the three assessors observed 'inappropriate collimation' and 'other body parts' on the images, which are most likely causes of the histogram error result.

4.4 IMAGE QUALITY OF IMAGE RECORDING TECHNIQUES

In this section, the results of the last part of the results of the checklist (Appendix A) are assessed, interpreted and discussed. As discussed in section 2.8.2, the seventh

element included in this study is the assessment of the EI values for the qualitative section (see Appendix I), categorised in qualitative themes (cf. 3.5), meaning it is intended to gain an understanding of underlying reasons, opinions and motivations.
First of all, there is no practical or general definition of image quality (Sandborg, 2017: 4). According to Sandborg (2017: 4), the quality of an image lies in "how well the image answers the question or solves the diagnostic task". Therefore, the quality of an image will vary with the requirements of the diagnostic task of the specific image. In this study, the requirements of image quality relate to chest and abdomen image contrast, density, distortion, noise level and degree of sharpness.
The three assessors rated the five areas of image quality regarding the PA/AP and LAT chest and erect and supine abdominal images using the following questions:

Subject 1: What was the radiographic contrast characteristic on the image?
Subject 2: What was the density/brightness characteristic on the image?
Subject 3: Was there any distortion on the image?
Subject 4: Was there any 'noise' on the image?
Subject 5: What was the degree of sharpness on the image?

<u>Qualifier rating 5 to 1 standards</u>
The following section contains the qualifier rating standard applied to the above questions (subjects 1 to 5). These ratings describe the standards of maximum to minimum prerequisite requirements (rating: 5 to 1) for each question.

5. Aspects of image quality exceed the expectations and show exemplary performance or understanding.
4. Aspects of image quality indicate some expectations exceeded and demonstrate solid performance or understanding.
3. Minimal competencies acceptable to meet the expectations. Performance and understanding are emerging with reflection of some errors.
2. Does not yet meet the acceptable standard and indicates that the image quality is not adequate to meet expectations. Serious errors, omissions or misconceptions.
1. Entirely not acceptable. Unacceptable image quality with no expectations met.

4.4.1 PA/AP and LAT chest

The following Table 4.3 illustrates the responses received for PA/AP chest (n=180) and LAT chest (n=180) to the question: 'What is the qualifier value and comments concerning image quality, being contrast, density, distortion, noise level and degree of sharpness in the images of the study?'

Table 4.3 Image quality average percentage results of PA/AP and LAT chest images of three assessors.

CHEST	IMAGE QUALITY	Not filled in	5	4	3	2	1
PA/AP	**Contrast**	0.4%	16%	61%	20%	2%	1%
	Density/brightness	0.2%	14%	60%	22%	3%	1%
	Distortion	0.2%	50%	26%	18%	3%	2%
	Noise level	0.2%	37%	59%	3%	0.2%	0.6%
	Degree of sharpness	0.4%	17%	56%	21%	3%	2%
LAT	**Contrast**	0.6%	8%	47%	26%	12%	6%
	Density/brightness	0.6%	8%	48%	23%	13%	7%
	Distortion	0.6%	51%	20%	24%	3%	2%
	Noise level	0.6%	36%	46%	16%	1%	0.2%
	Degree of sharpness	1%	7%	47%	27%	12%	5%

Subject 1: Contrast in PA/AP and LAT chest images.

The assessors gave PA/AP chest images contrast a qualifier of 4 with 61%, indicating that the image quality exceeded some expectations and demonstrated solid performance or understanding, as indicated in Table 4.3. The most frequent contrast qualifier in LAT chest images was also 4, which indicated 47%. Compared with PA/AP chest images, a total of 12% had a qualifier result of 2, and 6% had 1, indicating a slight increase in the problems with contrast meeting acceptable standards or inadequate expectations, errors/omissions or misconceptions. Image quality expectations showing exemplary performance was only evident in 8% LAT chest images.

Eighteen percent of PA/AP chest images required more exposure to increase the contrast, compared to 36% of LAT chest images, indicated by the comments given by the assessors. Post-processing contrast with window levelling is possible in CR imaging, nevertheless, not always possible with inappropriate exposure given to the chest and abdomen image under examination. Enfinger (2015: 31) stated that when the processing algorithm is manipulated in the raw data, it can be interpreted as an increase in scattered x-ray photons, which appear as an 'overexposed' image. The computer therefore do what it is programmed to do with any overexposure: it manipulates the final image to appear lighter. Section 2.3.1 of the literature review indicates that if contrast is too low, the noise (CNR) is too high. Therefore, it can be concluded that too little exposure was used with LAT chest images, which resulted in a grainy appearance due to quantum mottle. A correlation can also be made with section 4.3.6, indicating the comparison of underexposure to EI values, showing that 45% of LAT chest images had too little EI values.

A computer cannot differentiate between overexposure and scatter, as specified by Enfinger (2015: 31). This is where the comment of the assessors, that 14% of the PA/AP chest and 21% of LAT chest images needed better collimation, links up. In other words, if the images had been collimated as required, scatter radiation would have been reduced. Hence, it would not have the result of increased EI values assessed (showing as overexposed images). Ultimately, incorrect collimation will darken the lower and outer portions of the image. Back scatter should be reduced by lowering the level of kV and producing proper collimation. Other comments specified that the contrast in 2% of PA/AP chest and 5% of LAT chest images was influenced by the size of the patients, while 2% of PA/AP chest and 5% of LAT chest images were due to the patient's condition/pathology.

Subject 2: Density/brightness in PA/AP and LAT chest images.

The highest percentage of density/brightness had a qualifier of 4, resulting in 60% of PA/AP chest images compared to 48% of LAT chest images. Regarding PA/AP chest images, the qualifier of 3 followed. A qualifier result of 3 occurred in 22% of PA/AP chest and 23% of LAT chest images, indicating that awareness should be made in radiology departments of some 'errors' made in achieving optimal density/brightness. The qualifier of 5 was at least agreed to with 14% of PA/AP chest images and 8% of LAT chest images that exceeded the expectations and show exemplary performance or understanding of.

Desai *et al*. (2010: online) state that density is directly proportional to the SNR in CR systems (cf. 2.3.1). The feedback from the assessors stated that 20% of the PA/AP chest images needed more exposure, compared to 36% of the LAT chest images. Limiting the amount of quantum mottle, thereby avoiding low exposures to reach the image receptor, is a common concern in CR, according to a whitepaper from ASRT (2012: 7). A concern raised, as reported with the contrast, indicated that 15% of PA/AP chest and 19% of LAT chest images needed collimation to improve the density in the PA/AP chest images, which is not correctly stated by the assessors.

Sufficient density/brightness is necessary in a quality image to display anatomical structures (cf. 2.9). It was also recorded that 4% of the LAT chest images that did not meet or exceed the minimum standard were due to the patient's chest size being excessively large. When a patient is positioned in the LAT projection, the 'thickness' of the anatomical part enlarges significantly compared to a PA/AP projection. Pongnapang (2005: 2) states that CR needs 20% more radiation exposure to keep the same SNR ratio as with a 200 speed film (cf. 2.3.1). More penetration is therefore essential with LAT chest images.

Subject 3: Distortion in PA/AP and LAT chest images.

Defined in section 2.8.1, distortion is a misrepresentation of the true size, shape or spatial relationship of an object in a radiographic image (Papp, 2006: 300). As shown in Table 4.3, similar results were recorded for distortion with PA/AP chest as with LAT chest images, these being 50% to 51%, with a qualifier of 5. Size and shape distortion were the most likely reasons for the remaining 50% not yet meeting the acceptable standard to meet expectations when observing PA/AP chest images. Of this 50% of PA/AP chest images, 9% of images were distorted due to positioning errors and rotation of anatomical parts, compared to 12% of LAT chest images. Of the PA/AP chest images, 3% were lordotic projections. The assessors also stated that 5% of the PA/AP chest and 10% of the LAT chest images had anatomical parts obscuring the ROI. Correct arranging of anatomical parts of interest, before exposure, needs to be considered more accurately by diagnostic radiographers.

Subject 4: Noise level in PA/AP and LAT chest images.

The noise level with a qualifier result of 4 indicated that 59% of PA/AP chest and 46% of LAT chest images showed aspects of image quality that indicated that expectations were exceeded and demonstrated solid performance or understanding in the result. PA/AP chest (37%) and LAT chest images (36%) had a qualifier of 5. Image quality, regarding noise levels, was therefore very high in both chest projection images. As mentioned earlier, 4 or 5 qualifier results demonstrate that the diagnostic radiographers are skilled in producing chest images. The assessors indicated that inappropriate collimation was the main reason for these images not meeting the required standards. Collimation was also noted as the key concern causing noise in LAT chest images, scoring 9%, whereas only 0.7% of PA/AP chest images were documented for collimation. With the feedback received from the assessors in relation to LAT chest images, 9% of the images indicated that exposure had an influence. Too little mAs in CR images produce noise images due to the quantum mottle effect (cf. 2.3.4). Quantum mottle was present in 0.4% of PA/AP chest and 4% of the final LAT chest images in total. As established previously (cf. 4.5.6.1), 22% of the LAT chest and 5% of the PA/AP chest images had quantum mottle and may be the reason for the noise.

The other qualifier results for 2 and 1, as shown in table 4.3, were 0.2% and 0.6% for PA/AP chest images. The assessors indicated that these low qualifier results referred to the ‘patient conditions and pathology in the image’ as well as ‘incorrect body parts in the required’. These conditions could have resulted in different absorption of the radiation, since it differs from normal lung tissue. Consequently, masses, lesions and other conditions could have had a thicker solidity, which therefore is also responsible for creating the appearance of quantum mottle in an image.

Subject 5: Degree of sharpness in PA/AP chest images.

The evidence in Table 4.3 shows that 56% of PA/AP chest and 47% of LAT chest images had a degree of sharpness qualifier of 4. Secondly, 27% of PA/AP chest images scored a 5, whereas 27% of LAT chest images received a qualifier of 3. However, a closer look at the findings indicates that the assessors stated that 17% of

PA/AP chest and 33% of LAT chest images needed more exposure to improve image sharpness and detail. Eight percent of PA/AP chest and 19% of all the LAT chest images were also indicted as having too little collimation applied. The too little collimation could have led to the low result of 21% of PA/AP images only having an image quality of 3. A qualifier of 3 indicates that the pixel value in the image was acceptable, but needed improvement.

4.4.2 Erect and supine abdomen

Table 4.4 following hereafter illustrates the responses for the erect abdominal (n=180) and supine abdominal (n=180) images to the question: 'What is the qualifier value and comments on image quality, namely, contrast, density, distortion, noise level and degree of sharpness in the images of the study?'

Table 4.4 Image quality percentage results of erect and supine abdominal images of three assessors.

ABDOMINAL	IMAGE QUALITY	Not filled in	5	4	3	2	1
ERECT	Contrast	0%	20%	59%	15%	5%	1%
	Density/brightness	0%	20%	58%	15%	5%	1%
	Distortion	0%	53%	30%	14%	2%	1%
	Noise level	0%	41%	50%	7%	0.7%	0.7%
	Degree of sharpness	0%	21%	55%	18%	5%	1%
SUPINE	Contrast	1%	18%	55%	21%	4%	1%
	Density/brightness	1%	18%	59%	16%	5%	1.%
	Distortion	1%	52%	28%	14%	3%	1%
	Noise level	1%	40%	53%	5%	0.4%	0.2%
	Degree of sharpness	1%	19%	57%	17%	5%	1%

Subject 1: Contrast in erect and supine abdominal images

The contrast result in erect abdominal images in Table 4.4 illustrates that only 5% had a qualifier of 2 and 1% of a qualifier of 1. Supine abdominal images reflected a total of 4% with a qualifier of 2 and 1% with a qualifier of 1. These low qualifier results indicated that erect and supine abdominal images regarding contrast, only warrant minor concern. Of the erect abdominal images 59% and 55% of the supine abdominal images received a qualifier of 4, which is a very good percentage of the total.

The assessors pointed out that 15% of the images needed an increase of kV in exposure to achieve a better contrast result. Abdomen thickness is a concern when examining the ROI. Adequate penetration is necessary as well as mAs in order to avoid quantum mottle. In the study, although satisfactory contrast was achieved, diagnostic radiographers should nonetheless still strive to improve by setting an exposure to meet the required outcome. It is important to acknowledge that during supine abdominal images when the patient is positioned, abdomen thickness decreases due to the supine position. Therefore, it should be noted that 13% of the supine abdominal images received too much exposure. Comparing this to the results previously discussed in section 4.4.6.1, where 52% of supine abdominal images were overexposed, it does not appear similar. Underexposed supine abdominal images were at 11%, as compared to the assessors' 9% result, indicating 'that mAs were needed in the exposure'. The contrasting results also confirm that 9% of erect abdominal images required collimation, compared to 11% of supine abdominal images. Collimation optimises erect and supine abdominal images, which is also linked to improving exposure results. As stated in Appendix O, accurate centring is vital for the most appropriate collimation. Incorrect collimation, as mentioned earlier with regard to LAT chest images, will darken the lower and outer portions of the image. Side collimation is therefore vital to reduce scattered radiation in erect abdominal images.

Subject 2: Density/brightness in erect and supine abdominal images

A total of 58% of erect abdominal images received a main qualifier of 4 for density/brightness, for supine abdominal images it was 59%. The qualifier of 5 followed with a result of 20% of erect abdominal and 18% of supine abdominal images, which reflected a satisfying image quality result. The density image quality readings confirmed that the qualifier of 2 and 1 for both abdominal projections were low as a percentage.

According to the comments made by the assessors 'adequate exposure' is essential since abdominal structures are superimposed and these relationships are critical to diagnose. For 8% of the supine abdominal images, it was suggested that the 'density/brightness level be lowered'. Many factors are at play, notably 'patient size', 'pathology', 'positioning' and 'exposure' in order to accomplish the requested suggestion. According to the study, 15% of the erect abdominal images needed an 'increase in exposure' to optimise the density significance. Hand in hand with exposure goes the important consideration to use correct collimation, where it was noted that 9% of the images required 'more collimation' for exposure to be optimised. Large patient size, noted as 6%, was also mentioned as a technical consideration since greater exposure is necessary to achieve good density differences between abdominal structures. Another aspect mentioned was that 5% of the images 'needed less density', consequently appearing 'too dark' for diagnosis. Slightly more than half of the assessed erect abdominal images (51%) were 'overexposed' (cf. 4.5.7.2). Diagnostic radiographers are responsible for exposure settings and overexposure can lead to increased density.

Subject 3: Distortion in erect and supine abdominal images

Distortion in erect abdominal images yielded aspects of image quality that exceeded the expectations and shows exemplary performance, resulting in 53% of erect abdominal and 52% of supine abdominal images with a qualifier result of 5. This was followed by a qualifier 4 for 30% of erect abdominal and 28% of supine abdominal images, as illustrated in Table 4.4. Assessors noted that the majority of the erect abdominal (5%) images assessed for distortion were due to ‘too little exposure’ given. Of the supine abdominal images, on the other hand, 5% required ‘an increase in exposure’ than that which was administered. These erect and supine images appeared distorted due to exposure faults. The assessors indicated that 3% of the total erect images showed ‘incorrect positioning’, which resulted in the apparent distortion. Since movement is voluntary or involuntary, it is important to be aware of the fact that distortion can be due to breathing, not standing when it is required and the condition of the patient during the examination. Good communication and low exposure time are necessary in cases where abdominal projections are concerned. Extended exposure time is required for abdomen image acquisition with potential motion artefacts, which present as image distortion (Seibert, 2009: 23). Therefore, a longer exposure time is in direct correlation with distortion.

Consequently, it should be noted that all these factors, namely breathing, exposure time and movement while standing can cause distortion, which is uncontrollable by the diagnostic radiographer performing the chest and abdominal examinations.

Subject 4: Noise level in erect and supine abdominal images

The study indicated that there are very few areas of concern with regard to noise since only 0.7% of erect abdominal images and 0.4% of supine abdominal images scored a noise level of 2. Erect and supine abdominal images had the same number of images (having noise) with a score of 1. According to the assessors, the noise level of the erect abdominal images was due to underexposure (4%), collimation (3%), patient size and grainy appearances (2%). There were infrequent comments given by the assessors on supine abdominal images regarding noise. One of the comments indicated that 1% of the supine abdominal images appeared overexposed in the ROI region, resulting in the appearance of a noise level.

Subject 5: Degree of sharpness in erect and supine abdominal images

The most affirmative score in the abdominal images was that 50% of the erect abdominal image indicated that the expectations of quality in some of the images exceeded and demonstrated solid performance or understanding, scoring a qualifier result of 4, while supine abdominal images reflected 53%. This indicates that half of the erect, and more than half of the supine abdominal images had expectable sharpness since the overall appearance of images was acceptable. A qualifier score of 5 was given to 41% of the erect abdominal and 40% of the supine abdominal images, exhibiting image quality that exceeded the expectations and showed exemplary performance. However, the assessors indicated that 13% of the erect abdominal images required increased exposure for image detail/sharpness, whereas exposure increase was needed in 13% of the supine abdominal images. Optimal collimation was achieved in 8% of the erect abdominal and 8% of the supine images. .

4.5 SUMMARY OF THE FINDINGS

In this chapter, answers to the three study questions were provided. The radiographic image recording techniques, using CR imaging systems, were presented in the research tool. Following here is a summary of the collected data.

The assessed data indicated that most of the sections of the checklist, namely part selection on CR workstations, use of a grid to avoid gridline artefacts, IP artefacts, plate reader artefacts, CR scanner malfunction, quantum mottle and histogram errors, reflected little cause for concern in optimising diagnostic images, which was due to an average occurrence rate of less than 10%.

However, identified areas for concern were collimation, the use of anatomical markers and exposure settings to establish the in-range EI values. Pre-processing techniques were not applied optimally in these areas. Another area requiring attention was the positioning of anatomical parts in relation to the collimation used. This ‘human error’, which resulted in averages higher than 60% of both chest (PA/AP and LAT) and abdomen (erect and supine) images, was evident. This is directly associated with the technical skills of the diagnostic radiographers. In relation to the artefacts identified on the chest and abdominal images, foreign objects on patients and quantum mottle were most frequently observed. Diagnostic radiographers at the radiology departments therefore need to improve techniques to avoid the occurrence of such artefacts.

Image quality produced satisfactory results relating to distortion, noise level and the degree of sharpness. However, the study identified that contrast and density technique could be improved upon. As far as these techniques are concerned, emphasis should be placed on the exposure setting efficiency of what type of image is selected and the collimation used before exposure. Patient assessment and preparation are therefore two key aspects of quality improvement.

Overall the study revealed that pre-processing techniques were not optimally applied. The findings determined that non-optimal techniques were not prevalent in any particular section but were spread out across all sections, which pointed to an above-acceptable level of non-optimal techniques. For this reason, specific recommendations are put forward in the chapter that follows.

Chapter 5 will summarise the research process followed during this research study. Thereby the research objectives will be attained and presented with components of the checklist results. Thereafter, a list of recommendations will be presented according to the conclusions made as a result of the study findings, with specific reference to the checklist implemented. Such recommendations will be specified with the intention to improve CR image recording techniques of radiology staff, in order to optimise image quality. The chapter will conclude by providing the limitations of the study as well as future research that may be required.

CHAPTER 5

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

Chapter 4 focused on the research findings, which were presented, analysed, interpreted and discussed. In this final chapter, the research conclusions have been formulated. Limitations of the study and related recommendations are provided. Specific recommendations to address identified shortcomings in the radiographers' radiographic image recording techniques with the use of CR systems will be given. The final conclusions along with the milestones from this research study are also formulated in finalisation of the chapter.

5.2 SUMMARY OF THE RESEARCH STUDY

The overall goal of the study was to examine CR image quality prior to post-processing and to ensure that optimal radiographic image recording techniques are followed when using CR image acquisition systems. In order to achieve this goal, an assessment was undertaken of the current CR image recording techniques at the respective private and government hospitals.

The aim of this study was to assess and possibly enhance image recording techniques employed when using computed radiography imaging systems in private and government hospitals in the Eastern Cape province.

The goal and aim of the study were addressed through the following research questions:

RQ_1: What CR image recording techniques are used at the specific private and government hospitals in the Eastern Cape province?

RQ_2: What radiographic image recording techniques have a potentially non-optimal influence on exposure index (EI) values?

RQ_3: What radiographic pre-processing techniques (e.g. positioning, collimation, exposure techniques etc.) need to be optimised during examinations performed using CR to ensure optimal diagnostic images?

The research objectives, which addressed the research questions through the use of a research tool − a self-designed checklist are outlined. The researcher and assessors were provided with information from the checklist with both quantitative and qualitative components. The section that follows highlights the conclusions reached from each research objective.

5.3 CONCLUSIONS AND RECOMMENDATIONS FROM RESEARCH TOOL: CHECKLIST

The following conclusions based on the objectives of the study, were pursued:

5.3.1 The identification of the CR image recording techniques used at private and government hospitals in the Eastern Cape Province.

The literature review identified image recording techniques (Agfa Healthcare NV, 2014; Carlton & Adler, 2013; Fauber, 2013; Papp, 2011; Seibert & Morin, 2011; Carter & Veale, 2010; CRCPD, 2008; Siegel & Kolodner, 1999), which the researcher used to create the self-designed checklist. The results of the study identified shortcomings relating to certain aspects of CR, such as 'part selection of anatomical parts' and 'avoiding of histogram errors'. In practical conditions with the use of CR, improved image quality primarily relies on the radiographer consistently applying good radiographic techniques, as described in the requirements for chest and abdomen imaging (see Appendix N and O). Correctly applied image recording techniques are just as important in CR as they are in conventional radiography in order to produce high quality images.

Incorrect positioning of the chest and abdominal projections revealed an undesirable affect on image quality (cf. 4.3.2). Accurate patient positioning is therefore one of the first areas identified where optimal image recording techniques were not correctly applied. Positioning of patients is the responsibility of the radiographer alone. Positioning errors have been identified in several studies as the principal reason for image repeats (ASRT, 2012: 12). Upon assessment of both projection images in this specific study, it was identified that a high percentage of non-optimal image recording techniques were due to inadequate collimation (cf. 4.3.3). Adequate and tight anatomical collimation for each radiographic projection is vital in producing high quality images of diagnostic value. Collimation is a radiographic technique that is used prior to exposure to ensure correct EI values and radiation protection. The technique of applying correct collimation therefore needs optimisation, as correct collimation is a pre-requisite for improving the diagnostic quality of the images.

A radiograph is considered a legal document and for it to be admissible in a court of law, it must show a correctly positioned radiopaque anatomical marker, as indicated in Chapter 2 (cf. 2.9.). The results (cf. 4.3.4) indicate that the majority of radiographs did not include a personal anatomical marker, which as a result indicate that this radiographic technique is not optimally utilised at the specific private and government hospitals in the Eastern Cape province that formed part of the study.

Hammerstrom, *et al*. (2006: 226) explain that, with regard to artefacts, the electronic components that form, transmit and store an image must all work in harmony if an image of optimal diagnostic quality is to be produced. Non-electronic components of the imaging chain, i.e. the cassette and imaging plate, may be the greatest source of image artefacts (cf. 4.3.5). The results indicated that the most frequent IP artefacts in both the chest and abdominal images were scratches and scuff marks. This is an indication of the poor quality of cassettes that can be ascribed to age and/or poor maintenance.

The most frequent foreign artefacts in both the chest and abdominal images were foreign objects on patients (cf. 4.3.5.3). Radiographers therefore do not practically ensure that optimal pre-processing techniques are applied by removing all foreign objects from patients. Furthermore, it was noted (cf. 4.3.5.4) that extraneous lines on both the chest and abdominal images could have been avoided, as noted by Shetty *et al.,* (2011:40) (cf. 2.9). Such lines may be due to dirt or dust specks over the light guide. Permanently active rollers result in CR scanner malfunction, which may cause skipped scan lines, missing pixels or distorted images (cf. 4.3.5.5).

The results also indicated that quantum mottle occurred (cf. 4.3.5.6). This may have occurred due to too little mAs being used in the exposures of the chest and abdominal images. Quantum mottle can unfortunately not be corrected during post-processing, as it is a product of too few photons being received, resulting in a grainy image.

Upon assessing all image recording techniques, it was concluded that the three key areas requiring attention were: (i) radiographic practice such as positioning, collimation and usage of personal anatomical markers, (ii) setting the exposure and (iii) avoiding artefacts through practical techniques. The following recommendations are made to address these findings.

5.3.2 The identification of the radiographic image recording techniques that have a non-optimal influence on EI values.

It should be noted that the majority of chest and abdomen images were presented within the standard EI ranges of AGFA Healthcare (cf. figure 2.5). However, overall the abdomen images had a higher number of overexposed images (cf. 4.3.6). The results therefore indicated that radiographers used a wide range of EIs at both hospitals, with most abdomen images being outside of the expected AGFA Healthcare EI range. The results highlight the importance of auditing EIs when using CR systems. The study also confirmed the correlation between incorrect 'part selection' at the CR workstations and the direct link to the occurrence of histogram errors. Non-optimal collimation, centring of anatomical parts and 'other body parts' recognised or identified in the chest and abdomen images, further contributed to histogram errors (cf. 4.3.7).

The study determined that, when assessing image quality with a qualifier result, PA/AP and LAT chest images had contrast and density/brightness image quality falling below an acceptable '3' qualifier value. The utmost care should be taken to ensure correct exposure and optimal collimation in chest image examinations in the radiology practices of the Eastern Cape (cf. 4.4.1). CR processors cannot differentiate between overexposures and scatter radiation and therefore require optimised collimation to improve contrast and density. Distortion and the degree of sharpness in the PA/AP chest seemed to be the most concerning (cf. 4.4.1).

Based on an assessment of the CXR results, too little exposure was used with LAT chest images, resulting in grainy images reflecting quantum mottle. The assessors noted poor image quality of LAT chest images due to the non-optimal rotation and positioning of anatomical parts. The assessors' feedback indicated that the LAT chest images needed an increase in the mAs during exposure as well as optimised collimation to the appropriate lung field in order to improve image sharpness and detail (cf. 4.4.1). The image quality results for erect abdomen images reflected a positive image qualifier, resulting in '3' and above for all sections. The study of supine and erect abdomen images (cf. 4.4.2) affirmed the fact that increased exposure will ensure proper penetration and give an enhanced contrast result.

Additional areas noted that should be focused upon in order to ensure density improvement were adequate collimation and the size of the patient. Improper positioning resulted in images appearing distorted. Saturated in the AOI region, erect abdomen images did indicate a noise level, as most erect abdomen images were noise free. More than 90% of erect abdomen images presented optimal sharpness and image detail (cf. 4.4.2).

5.3.3 The development of recommendations to inform guidelines for optimising diagnostic images.

The following section focuses on the recommendations based on the conclusions in Chapter 4. Four sections, namely: functional, technical, practical, and quality assurance recommendations are proposed. The recommendations included in this study may be used as a resource for radiographers performing chest and abdominal CR system radiography examinations.

The aim is to further optimise image recording techniques in radiology departments for chest (PA/AP and LAT) and abdomen (erect and supine) images. The recommendations are as follow:

A. Functional recommendations

Functional recommendations refer to what is expected from CR systems. In informal terms, it could simply be stated as "the system should get input A and give output X". The functional requirements include:

- *Continuous servicing of CR processor equipment*: This is necessary to avoid the malfunctioning of the rollers, which may result in faulty scanning. Equipment servicing must form part of the quality control programme in a radiological department. The processors should also be fitted with standby modes to ensure that the rollers do not produce skipped scan lines, missing pixels and distorted images (Shetty *et al.*, 2010:40).

- *Acceptable lists of EI values*: These should be displayed at every computer where processing takes place. Radiographers should be continuously made aware of these values (Adams, E., 2015: 22).
- *Up-to-date CR exposure charts that include patient body size and age:* These are a necessity in radiology practices. Exposure charts provide a guideline to radiographers for correct exposure (ASRT, 2012: 8).

Optimising adult technique charts based on projection, patient body size and age is required. Referring to exposure charts for sufficient density/brightness is necessary for a quality image in order to display different anatomical structures. A comprehensive exposure technique chart should include, at a minimum, the following variables for each x-ray tube:

i. Acceptable exposure indicator range (EI) according to size and age, which indicate what ranges are acceptable (exp. EI of 100 to 300 and in between).
ii. Target exposure range, which indicate what specific EI value should be achieved with a specific exposure.
iii. Source-to-image receptor distance (SID).
iv. Use of grid or no grid.
v. Focal spot size.
vi. Size of patient (small, medium, large, extra-large).
vii. kV.
viii. mAs.

Routine use of such charts would ensure consistent and accurate radiation exposure to the image receptor, thereby reducing patient dose (ASRT, 2012: 9).

B. Technical recommendations

Technical requirements are based on the product requirement of the CR system, therefore to be executed by the radiographers for correct usage.

- Best practice requires selecting the correct algorithm for the patient's projection prior to processing. It is the radiographer's responsibility to select the correct algorithm for the projection being examined, as required by CR quality standards.
- Artefacts on the rollers, such as dirt, need to be cleaned immediately to avoid reoccurrence of the artefact. Approved IP cleaners should be used when cleaning the IP. Excessive cleaning should be avoided since it can damage the protective coating of the IP and contribute to wear and tear. Drying the IP is important before re-inserting it in the cassette. This should be done by using a dry, lint-free cloth or by placing the IP in an upright position to air-dry.
- Periodic cleaning of the light guide and beam deflector by the personnel of the radiographic department should be ensured.
- EI auditing will assist with image quality improvements by identifying important factors such as collimation and present patient dose reduction.

C. Practical recommendations

Practical recommendations refer to the responsibilities of the radiographer performing the examination.

Positioning patients is the sole responsibility of the diagnostic radiographer, therefore particular attention should be paid when positioning the patients (Bontrager & Lampignano, 2014: 15). The utmost care needs to be taken in order to reduce unnecessary exposure of the patients. Results recorded in this study could be implemented as part of a progress plan for radiographers joining the department in the future. The progress plan could be used as a management technique for regular status reports, noting the achievements of the radiographers for the period ending, outlining the goals and objectives for the next reporting period and any problems which occurred that require improvement. The proposed progress plan could raise awareness of the issue of radiographers' performance.

Collimation is an important factor that needs to be given due consideration. Collimation should be kept to the soft tissue, outside the relevant anatomy, to prevent any exposure to the image receptor. Unnecessary exposure to the image receptor will result in the CR processor analysing all of the captured data and therefore attempting to adjust it accordingly (Bontrager & Lampignano, 2014: 40). Radiation protection alert signs should be displayed to remind radiographers to concentrate on collimating during examinations. Radiographers have the sole responsibility of deciding whether to collimate before the exposure is made, or to avoid it since it's a 'post-processing benefit'. Lead shielding is also an option when examining a chest radiograph (ASRT. 2010: 10). Evidently, as reflected in the results, it was noted that radiographers do use lead shields. Nevertheless, it needs to be positioned to not obscure the ROI. Lead shields not only protect the patient, but also provide a barrier from unnecessary exposure reaching the cassette.

Every radiographer is required to have their own personal anatomical marker (Enfinger, 2015: 49). Hospitals should contact a manufacturing company to assist in the provision of these anatomical markers. Hospitals should also have back-up anatomical markers to use when radiographers have misplaced or lost their own. In addition, hospitals need to enforce the rule that no image will be accepted without an anatomical marker. For CR image optimisation, a personal lead marker should be used consistently by the radiographers performing chest and abdomen images or any other projection, for that matter. A radiograph without lead markers on the original image during radiographic exposure should not be accepted by radiologists or doctors when reviewed. A standard set rule should apply in the radiology departments regarding this matter.

Radiographers must ensure that patients undress and wear hospital gowns before an examination can take place. It is the radiographer's responsibility to ensure that all unnecessary objects have been removed from the patient before the examination takes place. Radiographers also need to pay greater attention to the positioning of anatomical parts in the ROI before exposure.

Considering all of the above practical recommendations, mentorship and in-service training can be useful tools to improve and optimise practical concerns (Donovan, 2010: 704-708).

D. Quality assurance recommendations

It is recommended that constant CR quality assurance – reject analysis programme records of the radiographers' techniques be kept. Records can be kept in a reject analysis programme (RAP) (Foos, Sehnert, Reiner, Siegel, Segal & Waldman, 2009: 89). Attention should be given to gridline artefacts in case the results adversely change. Implementing a quality control programme for staff members to operate the system will remind and motivate them to optimise image quality. Training of new staff members is also key.

A CR quality assurance measure should be implemented, requiring radiographers to produce regular reject analysis reports by entering reject figures into a database. This should ensure that the hospital maintains consistent image quality and also minimise patient dosage by monitoring dose variation on every exposure and in analysing rejected images. As indicated by AGFA Healthcare (2014: 6), a report analysing rejected images (e.g. rejection reason, technologist's name and date) can be created for further investigation.

Standardised reasons for rejection should include the following, as recommended by Jones, *et al.* (2015: 6661):

1. **Positioning**
    a. Rotation
    b. Anatomy cut off
    c. Incorrect projection
    d. Incorrect marker
2. **Exposure error**
    a. Overexposure
    b. Underexposure
3. **Grid error**
    a. Cut off
    b. Decentring
    c. No grid
    d. Grid lines
4. **System error**
5. **Artefact**
    a. Detector
    b. Foreign object (jewellery, clothing, etc.)
    c. Contrast media
    d. Table/support/x-ray tube

6. **Patient motion**
7. **Test images**
8. **Study cancelled**
9. **Other**

Rejected image rates should be analysed and documented at least quarterly, but preferably monthly, and kept for a period of one year or the length of time required by the applicable regulatory agencies. Any corrective action taken in response to abnormally low or high rejected image rates should be documented, along with the results of the corrective action (Jones *et al*., 2015: 6661). Radiographers are directly responsible for optimal radiographic techniques. A reject analysis programme (RAP) is needed in radiology practices, as mentioned already.

Based on the results of this study, the radiographic departments should make posters to demonstrate where improved performance is required for chest and abdomen images. The posters will present examples of non-optimal techniques with the aim of raising the awareness of the radiographers in an attempt to encourage improved practice. A prime example of this would be to exclude unnecessary body parts from the examination. The monitoring of radiographers through a quality control plan needs to be implemented. This quality control plan could serve as a reminder to radiographers to optimise radiographic pre-processing techniques.

5.4 RESEARCH DESIGN

A retrospective design was followed to assess the quality of specific images using a checklist formulated by the researcher. Creswell (2014: 247) explains that quantitative research allows for the testing of objective theories by examining the relationship between variables, as discussed in section 3.2. Qualitative elements in the study have provided insight into the problem under investigation or helped to develop ideas for potential quantitative research (Wyse, 2011: 1).

5.5 VALIDITY AND RELIABILITY

Validity refers to the extent to which a research measure actually captures the meaning of the concept it is intended to measure (Abbott & McKinney, 2013: 81), as mentioned in section 3.3.6. Based on the findings and discussion in Chapter 4, it was possible to draw conclusions about the study objectives (cf. 5.3). It can therefore be stated that the checklist used as the research instrument did measure what it was intended to measure.

Reliability is the extent to which a research measure consistently evaluates a concept (Abbott & McKinney, 2013: 81). Consistent evaluation of the qualified diagnostic radiographers' images was ensured by the three assessors taking part in the study. Reliability was ensured by the evaluation of the checklist, verifying that it was free of measurement error (e.g. incorrectly worded items, etc.), as mentioned in section

3.3.6.2. A pilot study (see Appendix B) to test the checklist before use also enhanced the reliability of the study. Discussing all the requirements for each category of the grading framework with the three assessors were also implemented for the sake of greater reliability. This discussion of the checklist ensured greater statistical accuracy and avoidance of bias.

5.6 SIGNIFICANCE OF THE FINDINGS

The significance of the findings of this research study relates to the improvement of non-optimal image recording techniques when using CR. The findings from this study highlights the fact that hospitals can benefit from this research study. The study benefits patients, radiology departments and radiographers. The patients benefit as there will be potentially less repeats that are caused by suboptimal image recording techniques. Radiology departments will benefit through radiography efficiency since they will be less likely to repeat chest and abdomen examinations. Similarly, registered practitioners are likely to benefit from improved efficiency as there would be less repeats, ultimately resulting in improved productivity. Students will most likely benefit from more optimal image recording techniques being emphasised, irrespective of CR. In general, quality assurance through the application of optimal radiographic techniques will remind radiographers of their professional responsibility. The recommendations should be applied continuously and consistently through training sessions where new staff will also be incorporated into a culture of optimisation.

5.7 GENERALISATION OF THE FINDINGS

The study focused on two hospitals in the Eastern Cape province. However, the study can be generalised and implemented at similar private and government hospitals that primarily services urban dwelling patients. The results of this study can easily be extrapolated to other private and public hospitals as the conditions and limitations (refer to section 5.8), which presented at these hospitals were not specific to the extent that it would influence the data. General trends or frequencies identified are therefore likely to repeat themselves elsewhere.

The research study used the most frequently used x-ray examinations, namely chest and abdomen. The reason for using the most frequent examinations was to assist with and provide a generalised overview of similar institutions. This would therefore improve the applicability of the recommendations to similar institutions.

5.8 LIMITATIONS OF THE STUDY

Limitations refer to shortcomings, conditions or influences that are outside of the control of the researcher and that may place restrictions on the research study. The following are limitations that have been identified in this research study:

- The government hospital was in the process of renewing their systems during the period when the study was conducted, namely mid-December 2015. This resulted in digital radiography completely replacing CR systems. This could be seen as a limiting factor as the study aimed to have a longer data collection period.
- The research tool used, the self-designed checklist, did not allow the assessors to indicate any additional areas of assessment. No additional limitations were identified on the checklist.
- The use of only three assessors in the research study may cause an element of bias and/or subjectivity.
- The study was limited to one government and one private hospital in the Eastern Cape province.
- Limited literature on image recording techniques with the use of CR was available.
- The acceptable EI range was not available in radiology departments and therefore radiographers performing examinations of chest (PA/AP and LAT) and abdomen (erect and supine) images could not assess their images correctly.

5.9 RECOMMENDATIONS FOR FURTHER STUDIES

As mentioned in section 5.3.3, recommendations for guidelines to optimise diagnostic images were addressed. Based on the functional-, technical-, practical- and quality assurance recommendations mentioned, the following are recommended for future studies:

The evaluation and optimisation of a 'technique chart', regarding 'patient body size' as well as 'age', will benefit the achievement of 'in range' EI values of exposures used in radiographic department(s).

An in-depth study concerning the practical responsibilities of radiographers performing the examinations is recommended. It is suggested that the study aims to prove or disprove the statement that: 'Mentorship and in-service training are useful tools to improve and optimise practical concerns'. These practical concerns include: collimation, use of personal anatomical markers and records of unnecessary radiographic repeats.

It is further recommended that a study regarding the technical issues of equipment in a radiography department is conducted. This study can be useful to determine whether the maintenance and care of equipment have any direct influence on image production tool to perceive if attention and concern should be specified to equipment maintenance and care. The results may lead to the improvement of burdens, such as artifacts and the loss of time when unplanned faults occur during image production.

A study on rejected image rate in a radiographic department relating to all views, not only chest (PA/AP) and abdomen (erect and supine) as is the case in this study, is highly recommended. Such a study has the potential to reveal the reason or reasons behind rejected images and whether image recording techniques need attention or not.

During the time that this current study was conducted, no visible educational material concerning image recording techniques in a radiographic department were on display or available to staff. It is suggested that educational material such as posters in appropriate areas for instance, be distributed. Once this has been done, it is recommended that a study be conducted to determine whether this intervention has any influence on the improvement of collimation, use of personal anatomical markers, practical positioning of patients and setting of exposure factors that will adhere to the EI value given ranges, as set out in this study.

5.10 FINAL CONCLUSION

Image recoding techniques are just as important in film-screen radiography as in the use of CR systems. The findings of this study confirm the importance of applying the prescribed radiographic techniques in order to produce optimal radiographs. The study highlights the importance of radiographers maintaining professional ethical working standards in order to ensure optimal patient care by reducing radiation doses.

Some of the more concerning factors determined by this study were incorrect collimation, incorrect use of anatomical markers and noncompliance when comparing EI value ranges given after exposure was made.

However, the most concerning finding of the study relates to the quality assurance aspect of CR systems. Image recording techniques prior to post-processing will always need optimisation and therefore, QA programs should be implemented. The question that arises is: “Will the QA programme have the potential to improve image recording techniques with the use of CR systems?”

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APPENDICES

Appendix A: Checklist of CR Image Recording Techniques

CR IMAGE RECORDING TECHNIQUES CHECKLIST

Name of hospital………………………………………

Date…………………………………………

Visit: ………………....X-ray no………….

Examination	**Chest PA/AP**	**Chest Lateral**	**Abdominal Supine**	**Abdominal Erect**

Part selection on CR workstation		**Comment**
Correct		
Incorrect		

Positioning of anatomical part	**Yes**	**No**
Centre of collimated area		

Collimation:	**Yes**	**No**
Applied		
Applied after processing		

Anatomical markers	**Yes**	**No**
Personal Anatomical markers		
CR markers used		
No anatomical markers used		

Artefacts:	**Yes**	**No**				
Grid lines						
IP artefacts			Cracks	Scratches	Scuff marks	
Foreign objects			Dirt	Objects on	Debris causing light-coloured image	
Plate reader			Extraneous line patterns			
CR scanner malfunction			Skipped scan lines		Missing pixels	Distorted image
Quantum Mottle			"Blotchy" appearance when low mAs are used			

EI values:	**Min**	**Max**
Extremities	**690**	**1378**
Chest	**345**	**689**
All "In Bucky work"	**172**	**344**

Reason: EI to low or high?

	Yes	No	
Overexposure			
Underexposure			
Within range			

Histogram errors	Yes	No	Comment
Large density differences (sandbag, parent immobilising)			
Large density differences (use of contrast media)			
Too little collimation			
Too much collimation			

Qualifier: 5: Excellent, **4**: Good, **3**: Average, **2**: Poor, **1**: Very Poor. **(Clarified below)**

Image quality	Qualifier	Comment
Contrast (relationship between raw pixel values and gray-scale levels)		
Density/brightness (determine the number of shades of gray)		
Distortion (shape and size of structures)		
Scatter noise/fogging		
Degree of sharpness		

5. Aspects of image quality exceed the expectations and show exemplary performance or understanding.
4. Aspects of image quality should indicate some expectations exceeded and demonstrate solid performance or understanding.

3. Minimal competencies acceptable to meet the expectations. Performance and understanding are emerging with reflection of some errors.
2. Does not yet meet the acceptable standard and indicates that the image quality is not adequate for expectations. Serious errors, omissions or misconceptions.
1. Entirely not acceptable. Unacceptable image quality with no expectations reached.

<u>In short</u> –

5. This is the **“Wow”**
4. This is a **“Yes”!!**
3. This is a **“On the right track, but…”**
2. This is a **“No, but…”**
1. This is a **“Not at all”**

Appendix B: Pilot study questionnaire

Date: ______________________ **EXAMINATION: ____________________________**

1. Part positioning

Required anatomy included? ______________________________________

Collimation applied? ____

2. Exposure: EI

In Range	Underexposed	Overexposed

3. Image quality

Brightness? ____

Contrast? ____

Sharpness to show detail: ____________________________________

Evidence of Artifacts on Image Plate

Removable Artifacts? __________________________________

Non-removable Artifacts? ______________________________

Mechanical Artifacts? __________________________________

Motion artifacts? _____________________________________

Distorted images? ____________________________________

Gridlines ____

Image Plate in cassette conditions ________________________

Image plate efficient erased (no previous remaining images)? ________

CR machine

Reading laser? _________________________________

Rollers looked after? _____________________________

Equipment looked after? ___________________________

Collimation: Applied NOT applied

4. Markers

Personal anatomical markers	CR markers	No markers

5. Correct algorithm

Part selected on the CR control panel

Appendix C: Consent form (1) for confidentiality agreement

STATEMENT OF CONFIDENTIALITY AGREEMENT

THE NEED FOR DIAGNOSTIC RADIOGRAPHY LECTURES OBSERVING THE RESEARCH STUDY TO PROVIDE OBSERVED INFORMATION MAINTAINING CONFIDENTIALITY

The information participating in the research study – Research Ethics Clearance Number: REC 230408-011 - was explained to me by the researcher, Mrs. C. Nel.

By signing this agreement, I understand and agree that:

- I hereby give consent to participate in the study.
- I understand what is expected of me.
- I am participating out of my own free will.
- I understand that there is no remuneration involved.
- I understand that respondents may withdraw from the study at any time if they so wish without negative consequences.
- I understand that personal information will be confidential and anonymous.
- I understand that autonomy will be respected.
- I understand that the recordings, transcripts and data of this interview can be used for future projects stemming from this current research.

You may contact the researcher at any time if you have questions about the research study at cell phone number 078 121 0769 or email address charnenel@yahoo.co.za. You may contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research subject.

The agreement signed will be made to keep personal information confidential. Absolute confidentiality will be guaranteed. Personal information may be disclosed if required by law.

Charné Nel

Full name of Participant

Charné Nel — 01/10/2015

Full name of Researcher — Date — Signature

Appendix D: Consent form (2) for confidentiality agreement

STATEMENT OF CONFIDENTIALITY AGREEMENT

THE NEED FOR DIAGNOSTIC RADIOGRAPHY LECTURES OBSERVING THE RESEARCH STUDY TO PROVIDE OBSERVED INFORMATION MAINTAINING CONFIDENTIALITY

The information participating in the research study – Research Ethics Clearance Number: REC 230408-011 - was explained to me by the researcher, Mrs. C. Nel.

By signing this agreement, I understand and agree that:

- I hereby give consent to participate in the study.
- I understand what is expected of me.
- I am participating out of my own free will.
- I understand that there is no remuneration involved.
- I understand that respondents may withdraw from the study at any time if they so wish without negative consequences.
- I understand that personal information will be confidential and anonymous.
- I understand that autonomy will be respected.
- I understand that the recordings, transcripts and data of this interview can be used for future projects stemming from this current research.

You may contact the researcher at any time if you have questions about the research study at cell phone number 078 121 0769 or email address charnenel@yahoo.co.za. You may contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research subject.

The agreement signed will be made to keep personal information confidential. Absolute confidentiality will be guaranteed. Personal information may be disclosed if required by law.

Thea Grobler	29 December 2015	
Full name of Participant	Date	Signature
Charné Nel	02/01/2016	
Full name of Researcher	Date	Signature

Appendix E: Consent form (3) for confidentiality agreement

STATEMENT OF CONFIDENTIALITY AGREEMENT

<u>THE NEED FOR DIAGNOSTIC RADIOGRAPHY LECTURES OBSERVING THE RESEARCH STUDY TO PROVIDE OBSERVED INFORMATION MAINTAINING CONFIDENTIALITY</u>

The information participating in the research study – Research Ethics Clearance Number: REC 230408-011 - was explained to me by the researcher, Mrs. C. Nel.

By signing this agreement, I understand and agree that:

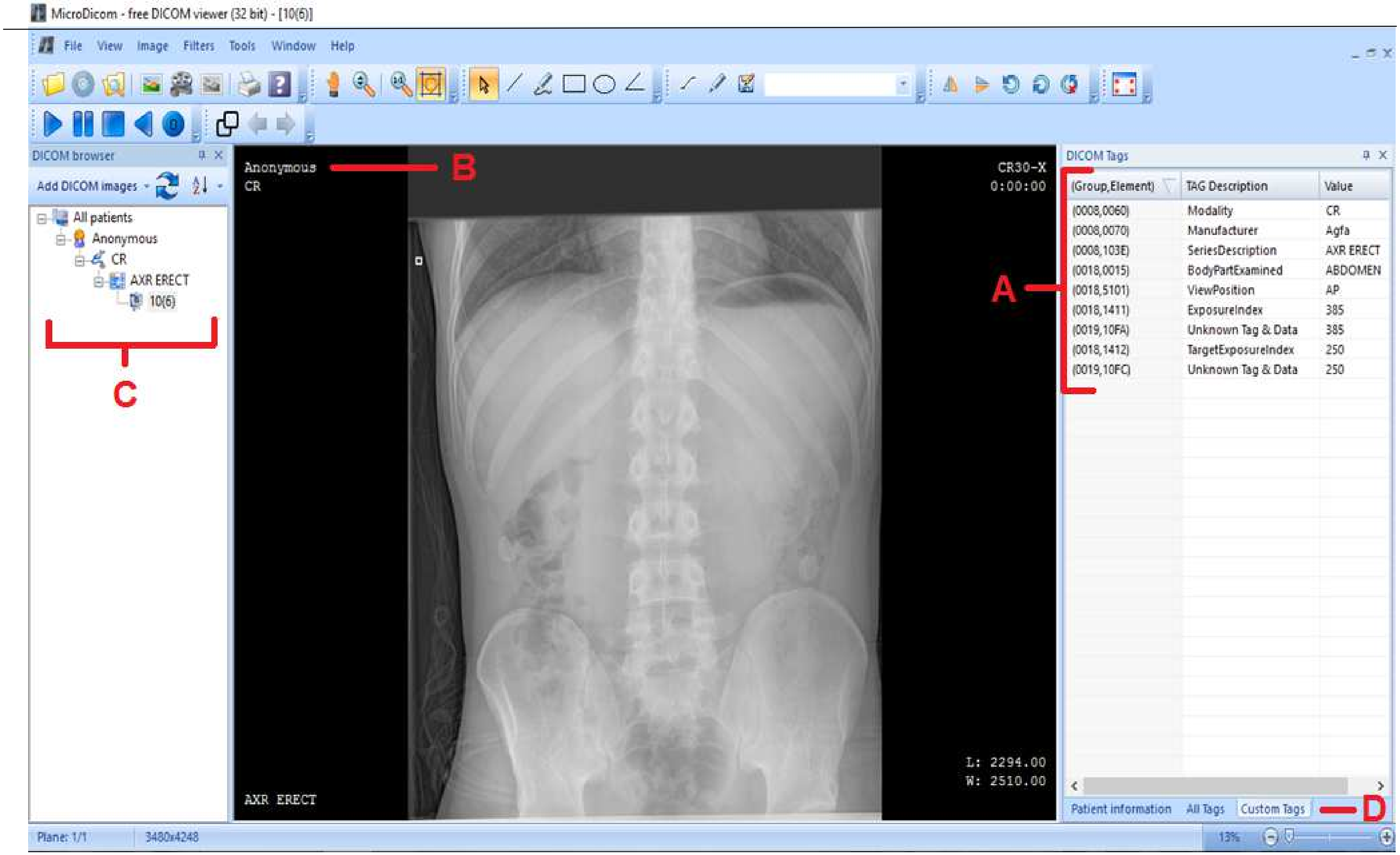
- I hereby give consent to participate in the study.
- I understand what is expected of me.
- I am participating out of my own free will.
- I understand that there is no remuneration involved.
- I understand that respondents may withdraw from the study at any time if they so wish without negative consequences.
- I understand that personal information will be confidential and anonymous.
- I understand that autonomy will be respected.
- I understand that the recordings, transcripts and data of this interview can be used for future projects stemming from this current research.

You may contact the researcher at any time if you have questions about the research study at cell phone number 078 121 0769 or email address charnenel@yahoo.co.za. You may contact the Secretariat of the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research subject.

The agreement signed will be made to keep personal information confidential. Absolute confidentiality will be guaranteed. Personal information may be disclosed if required by law.

Barbra Roux	29.12.2015	
Full name of Participant	Date	Signature
Charné Nel	02/01/2016	
Full name of Researcher	Date	Signature

Appendix F: MicroDicom layout



A: What is being looked at?

GROUP ELEMENT CODE	TAG DESCRIPTION	VALUE
(0008,0060)	Modality	CR
(0008,0070)	Manufacturer	Agfa
(0008,103E)	Series description	AXR ERECT
(0018,0015)	Body part examined	ABDOMEN
(0018,5101)	View position	AP
(0018,1411)	Exposure index (EI)	385
(0019,10FA)	Unknown tag & data – same as above	385
(0018,1412)	Target exposure index	250
(0019,10FC)	Unknown tag & data – same as above	250

B: Anonymous information regarding patient information. Confidentiality was taken seriously.

C: As noted, displayed is a direct portrayal of 'what type of image', including the numeral character, was being assessed by the three assessors.

D: Custom tags – is a demonstration of the area where group element codes were reserved from the "All tags" list (see section "A"). This method facilitated and simplified the assessment of all chest and abdomen images.

Appendix G: Completed checklist copy

CR IMAGE RECORDING TECHNIQUES CHECKLIST

Name of hospital: FRERE HOSPITAL

Date: Government

Visit: Week 1 X-ray no. 1(1)

Examination	Chest PA	~~Chest Lateral~~	Abdominal Supine	Abdominal Erect

Part selection on CR workstation

		Comment
Correct	✓	
Incorrect		

Positioning of anatomical part	Yes	No
Centre of collimated area		✓

Collimation:	Yes	No
Applied		✓
Applied after processing		✓

Anatomical markers	Yes	No
Personal Anatomical markers used		✓
CR markers used		✓
No anatomical markers used	✓	

Artefacts:	Yes	No				
Grid lines		✓				
IP artefacts		✓	Cracks	Scratches	Scuff marks	
Foreign objects	✓		Dirt	Objects on patient ✓	Debris causing light-coloured image	
Plate reader		✓	Extraneous line patterns			
CR scanner malfunction		✓	Skipped scan lines		Missing pixels	Distorted image
Quantum Mottle	✓		"Blotchy" appearance when low mAs is used			

Histogram errors	Yes	No	Comment
Large density differences (sandbag, parent immobilising)		✓	

EI values:	Min	Max
Extremities	690	1378
Chest	345	689
All "In Bucky work"	172	344

Reason: EI to low or high?

	Yes	No	EI 159 TEI 524
Overexposure		✓	
Underexposure	✓		
Within range			

Large density differences (use of contrast media)		✓	
Too little collimation	✓		Inf a Ant.
Too much collimation		✓	

Qualifier: 5: Excellent, **4**: Good, **3**: Average, **2**: Poor, **1**: Very Poor. **(Clarified below)**

Image quality	Qualifier	Comment
Contrast (relationship between raw pixel values and gray-scale levels	3	Not much difference
Density/brightness (determine the number of shades of gray)	3	~~Very~~ Few.
Distortion (shape and size of structures)	3.	Post Ribs rotated.
Noise level	~~3~~ 2.	Blotchy appearance.
Degree of sharpness	3	Due to noise lung markings not clearly visible.

5. Aspects of image quality exceed the expectations and show exemplary performance or understanding
4. Aspects of image quality should indicate some expectations exceeded and demonstrate solid performance or understanding
3. Minimal competencies acceptable to meet the expectations. Performance and understanding are emerging with reflection of some errors
2. Does not yet meet the acceptable standard and indicates that the image quality is not adequate for expectations. Serious errors, omissions or misconceptions
1. Entirely not acceptable. Unacceptable image quality with no expectations reached.

In short –

5. This is the **"Wow"**
4. This is a **"Yes"!!**
3. This is a **"On the right track, but..."**
2. This is a **"No, but..."**
1. This is a **"Not at all"**

Appendix H: Excel Sheet of results

Appendix I: Qualitative themes

CATEGORY	Image quality Contrast	Image quality Density/brightness	Image quality Distortion	Image quality Noise level	Image quality Degree of sharpness
Key words/Themes	Too much mAs used	Needs **MORE** exposure to increase density	Breathing distortion	Moiré Pattern effect - low frequency grid used	Needs more exposure for sharpness/ image detail
	Needs more mAs	Needs more collimation for good exposure with better density	Gridline distortion	Blotchy appearance of soft tissue (due to Quantum mottle)	Too much exposure used
	Needs **MORE** exposure to increase contrast	Needs less density	Looks distorted due to centering	Blotchy appearance of anatomical parts (due to Quantum mottle)	Missed section on image
	Needs more collimation for good exposure with better contrast	Due to incorrect study selected on CR	Looks distorted due to wrong low exposure	Lung markings appear blurry	Breathing unsharpness
	Due to incorrect study selected on CR	Due to patient condition/ pathology	Missed section on image	Saturation in inferior middle post zone	Needs better collimation
	Large patient size	Unnecessary anatomical part on image	Anatomical parts obscuring AREA OF INTEREST	Grainy appearance	Positioning error

CATEGORY	Image quality **Contrast**	Image quality **Density/brightness**	Image quality **Distortion**	Image quality **Noise level**	Image quality **Degree of sharpness**
Key words/Themes	Cardiomegaly with patient contrast	Large patient size	Diaphragms not sharp of clear. PELVIS , Liver not clear visible	Due to exposure	Due to patient condition/ pathology
	Due to patient condition/ pathology	Cardiomegaly with patient contrast	Rotation of anatomical parts = Pathology	Due to collimation	Unnecessary anatomical part on image
	Missed piece on image	Little (few) differences in grey scale levels in lungs	Rotations/ positioning of anatomical parts	Due to patient size	Due to movement (MOTION UNSHARPNESS) Bowel motion
	Unnecessary anatomical part on image	Lung markings not clearly visible	Not full inspiration	Due to incorrect study selected on CR	Due to patient size
	Breathing distortion	Hard to evaluate with the movement	Lordotic view / Apical clavicle view	Gridlines	Outlines of ribs not optimally sharp
	Due to patient positioning		Patient movement/MOTION DISTORTION	Incorrect body parts on the image	Lung markings not clear and sharp
	CXR needs a wide exposure latitude		Rib margin not sharp (on Lat view - not superimposed)	Due to patient condition/ pathology	Geometric unsharpness
	Only subtle differences with gray scale levels		Image divided into two columns		Due to noise

CATEGORY	Image quality Contrast	Image quality Distortion	Image quality Degree of sharpness
Key words/Themes	Hard to evaluate with the movement	Large patient or incorrect FFD	Margins of anatomical parts not visible (DUE TO QUANTOM MOTTLE)
	Due to upper lungs	Artifact (like a marker) over anatomy	DUE TO SATURATION
		Wrong positioning	Due to artifact
		ANATOMY Cut off	BREASTS caused lower lung fields inadequately penetrated
			Posterior ribs prominent
			Diaphragm(CHEST) Bowel (ABDO) not clearly visible
			CHOPPED IMAGE

Appendix J: CUT Central Research Committee Approval

Central University of Technology, Free State

ASSESSMENTAND GRADUATION UNIT

2016-06-03

Mrs C Nel
PO Box 2998
Beacon Bay
EAST LONDON
5205

Dear Mrs Nel

M TECH: RADIOGRAPHY: APPROVAL OF THE TITLE OF A PROPOSED RESEARCH PROJECT

TITLE: "Radiographic Image Recording Techniques when using Computed Radiography Imaging Systems in the Eastern Cape Province."

It is my pleasure to inform you that the Central Research Committee of the CUT approved the above project title on 2016-02-11.

For any enquiries please contact RE Phantsi at 051-507 3405.

Kind regards

pp REGISTRAR
DR N MRWETYANA

Copies to:	Prof H Friedrich-Nel	(Head of Department: Clinical Sciences)
	Prof LOK Lategan	(Dean: Research and Innovation)
	Mr J Kabamba	(Senior Director: Library and Information Centre)

20 Pres. Brand Street, Bloemfontein, South Africa, 9301 • www.cut.ac.za
Private Bag X20539, Bloemfontein, South Africa, 9300

Appendix K: Permission request letter Chief Executive Officer: Frere Hospital

P.O. Box 2998

Beacon Bay

East London

South Africa

Eastern Cape

5205

Date: ……………..…………

Chief Executive Officer: Frere Hospital

Amalinda Drive

Amalinda

East London

South Africa

Eastern Cape

5205

Dear Sir

Request for permission to conduct a research study

As a student at the Central University of Technology (CUT) in the Free State, permission is required for my M-tech research study. The title of this study is: **RADIOGRAPHIC IMAGE RECORDING TECHNIQUES WHEN USING COMPUTED RADIOGRAPHY IMAGING SYSTEMS IN THE EASTERN CAPE PROVINCE.** The purpose of this letter is thus to request permission to conduct the study.

The overall goal of the study is to ensure optimal radiographic image recording techniques with the use of CR image acquisition systems prior to post processing. The following will facilitate this:

- Analysing the current CR image recording techniques used at Frere and the Private hospital.
- Evaluating radiographic image recording techniques that have a potential non-optimal influence on EI values.

➢ Developing recommendations from trends that will help improve the image recording techniques using the CR imaging system.

I am requesting access to the NX workstations and PACS to record Exposure Indices of specific examinations. Access would also allow the researcher to evaluate the image recording techniques of images produced in the radiology department. Patient confidentiality will be maintained and perceived as anonymous, meaning that no patient identification or address will be used. Images will be evaluated to ensure correct collimation, anatomical markers placed and exposure given (in the form of EI – Exposure Index values).The research information from NX workstations will be collected in the year of 2015 and 2016. After recommendations and a HPCSA CPD talk has been given, optimal image recording techniques are expected for diagnostic purposes.

You may contact the researcher any time if you have questions about the research study or you may contact the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research participant.

A research report will be submitted to all participating hospitals. Thank you for your consideration in this matter. For any enquiries, please do not hesitate to contact me.

Charne Nel
(mobile: 078 121 0769)
Researcher

Dr RW Botha
Supervisor

Appendix L: Permission request letter Chief radiologist: Life Hospital

P.O. Box 2998
Beacon Bay
East London
Eastern Cape
South Africa
5205

Date: ……………

Chief radiologist: Life Hospital
32 Quenera Drive
Beacon Bay
East London
Eastern Cape
South Africa
5241

Dear Sir

Request for permission to conduct a research study

As a student at the Central University of Technology (CUT) in the Free State, permission is required for my M-tech research study. The title of this study is: **RADIOGRAPHIC IMAGE RECORDING TECHNIQUES WHEN USING COMPUTED RADIOGRAPHY IMAGING SYSTEMS IN THE EASTERN CAPE PROVINCE.** The purpose of this letter is thus to request permission to conduct the study.

The overall goal of the study is to ensure optimal radiographic image recording techniques with the use of CR image acquisition systems prior to post processing. The following will facilitate this:

- Analysing the current CR image recording techniques used at Frere and the Private hospital.
- Evaluating radiographic image recording techniques that have a potential non-optimal influence on EI values.

➢ Developing recommendations from trends that will help improve the image recording techniques using the CR imaging system.

I am requesting access to the NX workstations and PACS to record Exposure Indices of specific examinations. Access would also allow the researcher to evaluate the image recording techniques of images produced in the radiology department. Patient confidentiality will be maintained and perceived as anonymous, meaning that no patient identification or address will be used. Images will be evaluated to ensure correct collimation, anatomical markers placed and exposure given (in the form of EI – Exposure Index values).The research information from NX workstations will be collected in the year of 2015 and 2016. After recommendations and a HPCSA CPD talk has been given, optimal image recording techniques are expected for diagnostic purposes.

You may contact the researcher any time if you have questions about the research study or you may contact the Ethics Committee of the Faculty of Health Sciences, UFS at telephone number (051) 4052812 if you have questions about your rights as a research participant.

A research report will be submitted to all participating hospitals. Thank you for your consideration in this matter. For any enquiries, please do not hesitate to contact me.

Charne Nel
(mobile: 078 121 0769)
Researcher

Dr RW Botha
Supervisor

Appendix M: UFS Ethics Permission Letter

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

[redacted]

IRB nr 00006240
REC Reference nr 230408-011
IORG0005187
FWA00012784

11 November 2015

MRS C NEL
DEPARTMENT OF CLINICAL SERVICES
CUT

Dear Mrs Nel

ECUFS NR 197/2015
MRS C NEL
PROJECT TITLE: RADIOGRAPHIC IMAGE RECORDING TECHNIQUES WHEN USING COMPUTED RADIOGRAPHY IMAGING SYSTEMS IN THE EASTERN CAPE PROVINCE

1. You are hereby kindly informed that, at the meeting held on 10 November 2015, the Ethics Committee approved the following project after all conditions have been met, when the title discrepancy between the application form and protocol was updated and the Evaluation Committee report were submitted.

2. The Committee must be informed of any serious adverse event and/or termination of the study.

3. Any amendment, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

4. A progress report should be submitted within one year of approval of long term studies and a final report at completion of both short term and long term studies.

5. Kindly use the ECUFS NR as reference in correspondence to the Ethics Committee Secretariat.

6. The Ethics Committee functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the Ethics Committee of the Faculty of Health Sciences.

Yours faithfully

DR SM LE GRANGE
CHAIR: ETHICS COMMITTEE

Cc: Dr René Botha

Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | F: +27 (0)51 444 4359 | E: ethicsfhs@ufs.ac.za
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

<u>How the chest x-rays were assessed:</u>

Bontrager & Lampignano (2014: 81-86, 91-93); Titley & Cosson (2013: 42-47); Bushberg, Seibert, Leidholdt & Boone (2012: 227).

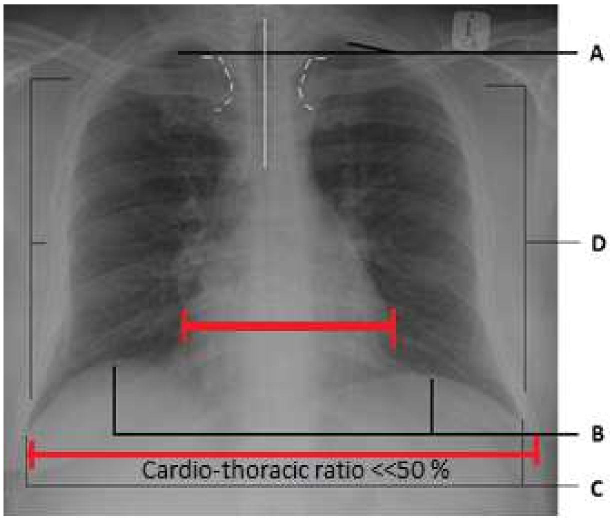


Figure 1: PA Chest radiograph

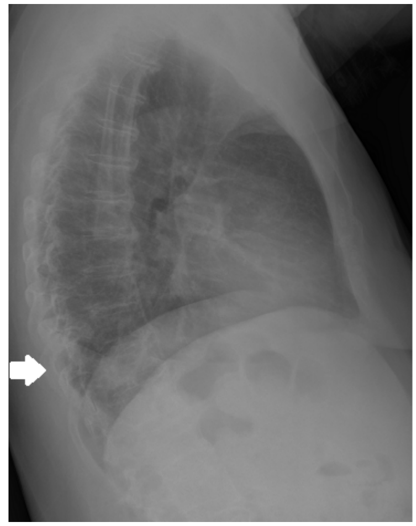


Figure 2: Lateral chest radiograph

<u>**Technical considerations**</u>

Technical considerations involved in the assessment of the radiographs were projection, positioning of anatomical parts of the chest, collimation, anatomical markers, artefacts & EI (penetration). Demographic information was not evaluated in this research study.

Projection

CR has image-processing algorithms that is used to align measured histogram values, after exposure has been made, with a predetermined look-up table (LUT) (Bushberg, Seibert, Leidholdt & Boone, 2012:227). The radiographer is responsible to select the exact examination, being a PA, AP or LAT chest when processing the exposed image to determine the incident radiation exposure to the detector in order to provide an EI value.

Patient positioning

The following anatomical boundaries should be clearly demonstrated (See Figure 1):

A. Apices

B. Diaphragm

C. Both lateral costophrenic angles

D. Both lateral chest walls

Correctly positioned PA chest (•) with contra indicators (○):

- Centre at thoracic vertebrae 6 or 7.
  - Apices chopped off
  - Diaphragm chopped
  - Unnecessary abdomen exposed
  - Costophrenic angles chopped and not demonstrated
  - Chest walls chopped off
- Medial sagittal plane (MSP) at 90 degrees to chest stand.
  - Causes rotation of the thorax
  - Small amount of heart not seen on the right
  - Both lung fields not of equal radiolucency
- Medial ends of clavicles equidistant to spinous processes of thoracic vertebrae (See Figure 1).
  - Variation of more than 1 cm could affect the appearance of the lungs
  - Rotation can cause differences in densities
  - Rotation can also cause a spurious increase in cardiac size and increased opacification at the lung bases owing to the overlying soft tissues
- Medial and lateral ends of both clavicles positioned on the same horizontal plane.
- Scapulae are located outside the lung fields with depressed shoulders.
  - Scapular densities can prevent detection of abnormalities in the periphery of the lung
  - Obscured apical region

Correctly positioned LAT chest (•) with contra indicators (○) (see Figure 2):

- Chin raised out of the image field
- Left side of the thorax adjacent to the image receptor
  - Causes rotation of the thorax
- Both arms raised above the head, preventing superimposition over the chest
- Centre at thoracic vertebrae 7
  - Apices chopped off
  - Diaphragm chopped

- Unnecessary abdomen exposed
- Costophrenic angles chopped and not demonstrated
- Chest walls chopped off

- Midsagittal plane must be perpendicular to the divergent beam (see Figure 2) white arrow – to allow correct positioning)
    - Inappropriate positioning can cause rotation

Collimation

Correctly collimated PA/AP chest (●) with contra indicators (○):

- Side collimated light fields to the outer skin margins on each side of the posterior chest surface with full inspiration
    - Chopped lateral chest walls
- Upper and lower light fields – adjust to include inspirated lung field
    - Chopped apices
    - Chopped costophrenic angles
    - Chopped diaphragm

Correctly collimated LAT chest (•) with contra indicators (○):

- Superiorly 5 cm above the shoulder joint
    - improper visualisation of the upper airways
- Inferior to the inferior border of the 12th rib
- Anteroposterior to the lever of the acromioclavicular joints

Anatomical side markers – right of left

Correct marker placement on a PA chest (●) with contra indicators (○):

- Correct anatomical marker should be visible and readable – should be placed reversed on cassette for PA chest and not obscure any chest anatomy
    - Ineffective patient safety
    - Error in constitutional standards
    - Latent conditions
    - There have been reports of chest drain insertion on the opposite side to a pneumothorax because of mislabelling

Correct marker placement on a LAT chest (•) with contra indicators (○):

- Correct anatomical marker should be visible and readable – should be placed reversed on cassette for LAT chest and not obscure any chest anatomy

- Ineffective patient safety
- Error in constitutional standards

Artifacts

- Patients should be undressed and free of any physical objects that may cause artifacts
    - Artifacts on images
- Irrelevant material should be removed from the area of interest when radiographing inpatients and performing portable examinations
    - External tubes and lines when doing portables in area of interest

Exposure and penetration - exposure index (EI)

The structures within the chest are composed of five (5) basic densities and are listed in order from the most radiolucent (dark) to the most radiopaque (light):

- ✓ *Air* – lungs are black on a radiograph because they are filled mainly with air
- ✓ *Fat* – Appears as dark shades of grey on a radiograph
- ✓ *Soft tissue* – Mainly heart and great vessels will appear white. Bronchi plugged with mucus and filled with fluid therefore will also appear white
- ✓ *Bone* – Composed mainly of calcium and makes bone appear grey to white
- ✓ *Metal* – *Metal is included since it is commonly seen in the body, example joint replacements. Metal absorbs more radiation than any other four (4) densities and will appear white on radiographs*

- Contrast, density and penetration should be sufficient
- kVp should be high and mAs low
    - Will not demonstrate the thoracic vertebrae and posterior ribs through the heart and mediastinal structures
    - mAs too long will cause movement unsharpness due to breathing
    - Exposure will not demonstrate a long scale of lung markings
- With the correct exposure factors, the end plates of the lower thoracic vertebral bodies should be just visible through the cardiac shadow
    - An under-penetrated film looks diffusely opaque (too white), structures behind the heart are obscured and left lower lobe pathology may be easily missed
    - An over-penetrated film looks diffusely lucent, the lungs appear blacker than usual and the vascular markings and lung detail is obscured

The radiographer has considerations to evaluate before submitting the radiograph for review, therefore the researcher and assessors will look at the following technical issues related to the use of CR.

Method utilised to assess the abdomen x-rays:

Bontrager & Lampignano (2014:31, 43, 83, 85, 104 - 123); Bushberg, Seibert, Leidholdt & Boone (2012:227).

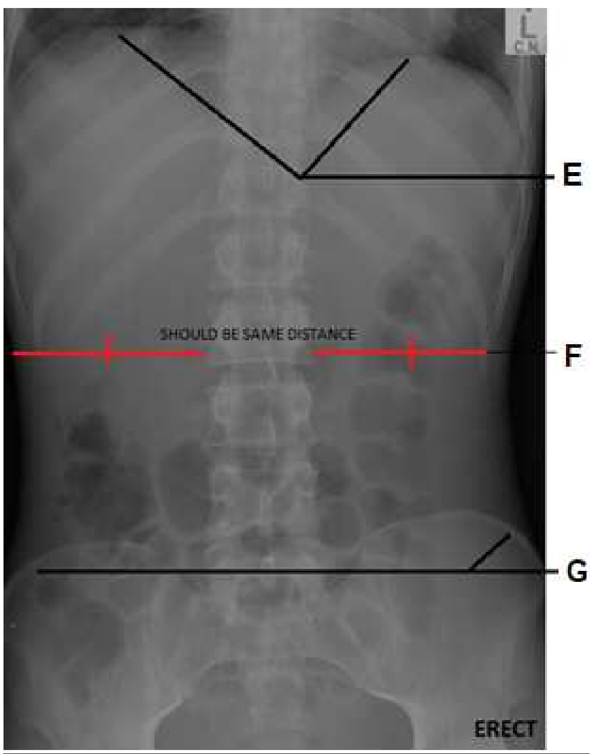


Figure 1: Erect abdomen radiograph

Figure 2: Supine abdomen radiograph.

Technical considerations

Technical considerations involved regarding the assessment of the radiographs was projection, positioning of anatomical parts of the chest, collimation, anatomical markers, artefacts and EI (penetration). Demographic information is not being evaluated in this research study.

Projection

CR has image-processing algorithms that is used to align measured histogram values, after exposure has been made, with a predetermined look-up table

(LUT).The radiographer is responsible to select the correct examination, being an ERECT or SUPINE abdomen when processing the exposed image to determine the incident radiation exposure to the detector in order to provide an 'exposure index' (EI) value.

Patient positioning

The following anatomical boundaries should be clearly demonstrated for the ERECT abdomen radiograph (See figure 1):

E. Bilateral Diaphragm should be included superiorly
F. Both lilac wing borders on lateral sides - in the middle
G. Outer rib margins should be the same distance from the spine

Abdominal radiographs are exposed on expiration, with the diaphragm in a superior position for better visualisation of abdominal structures

Correctly positioned ERECT abdomen (•) with contra indicators (○):

- Cassette (35 X 43 cm for adults) should be placed 5 cm above iliac crest
    - Diaphragm will not be included
- Centre at inferior costal (rib) margin (level of L2-L3)
    - Diaphragm chopped off
    - Will not include as much of the lower abdomen
- Medial sagittal plane (MSP) of body centred to midline of table or erect Bucky
    - Causes rotation of the abdomen
    - Causes rotation of the anterior superior iliac spine (ASIS)
    - Source-to-image (SID) should be 100 cm

The following anatomical boundaries should be clearly demonstrated for the SUPINE abdomen radiograph (See Figure 2):

H. Symphysis pubis
I. Outer rib margins should be the same distance from the spine

Abdominal radiographs are exposed on expiration, with the diaphragm in a superior position for better visualisation of abdominal structures

Correctly positioned SUPINE abdomen (•) with contra indicators (○):

- Cassette (35 X 43 cm) should be placed 5 cm above iliac crest
    - Diaphragm will not be included
- Centre at level of iliac crests (level of L4-5 vertebral interspace)
    - Not at the mid-abdominal level

- Diaphragm chopped off
- Will not include as much of the lower abdomen

- Medial sagittal plane (MSP) of body centred to midline of table or supine Bucky
    - Causes rotation of the abdomen
    - Causes rotation of intestinal structures
    - Causes rotation of the pelvis and iliac wings

Collimation

Collimate to include as much abdomen as possible

Correctly collimated ERECT abdomen (•) with contra indicators (○):

- Accurate centring is most important
- Side collimated light fields to the outer skin margins on each side of the abdominal surface with full expiration
    - Chopped iliac wings
    - Chopped anatomy of abdomen
- Upper and lower light fields – adjust to include expired lung field
    - Chopped diaphragm

Correctly collimated SUPINE abdomen (•) with contra indicators (○):

- Accurate centring is most important
- Side collimated light fields to the outer skin margins on each side of the abdominal surface with full expiration
    - Chopped iliac wings
    - Chopped anatomy of abdomen
- Upper and lower light fields – should be at full expiration
    - Involuntary motion of bowel if not on full expiration
    - Chopped symphysis pubis

Anatomical side markers – right of left

Correct marker placement on an ERECT and SUPINE abdomen (•) with contra indicators (○):

- Correct anatomical marker should be visible and readable
    - Ineffective patient safety
    - Latent conditions
- Markers should be placed out of area of interest

- Superimposing abdominal structures
- Markers should be placed before exposure
    - Error in constitutional standards

Artifacts

- Patients should be undressed and free of any physical objects to cause artifacts
    - Artifacts on images
- Irrelevant material should be removed from the area of interest when radiographing inpatients and portable examinations
    - External tubes and lines when doing portables in area of interest

Exposure and penetration - Exposure Index (EI)

The structures within the chest are composed of five (5) basic densities and are listed in order from the most radiolucent (dark) to the most radiopaque (light):

✓ *Air* – gas is black on a radiograph because they are filled mainly with air

✓ *Fat* – Appears dark shades of grey on a radiograph

✓ *Soft tissue* – Spleen and psoas muscle appears grey. Aorta, gall stones, pancreas and urinary tract stones will appear white

✓ *Bone* – Composed mainly of calcium and makes bone appear grey to white

✓ *Metal* – Metal is included since it is commonly seen in the body, example joint replacements. Metal absorbs more radiation than any other four (4) densities and will appear white on radiographs

Exposure (mAs) and long-scale contrast (kVp) and penetration should be sufficient to demonstrate psoas muscle outlines, lumbar transverse processes and ribs. Margins of liver and kidneys should be visible on smaller to average-sized patients. Slightly less overall density (brightness) on an erect abdomen than a supine abdomen is preferred.

OVER EXPOSURE = Too white/light

UNDER EXPOSURE= Too black/dark

- Contrast, density and penetration should be sufficient
    - Will not see
- Lowest exposure factors required to obtain a diagnostic image
- Highest kV and lowest mAs will result in required image quality that is necessary
    - Will not demonstrate the organs and soft tissue above
    - mAs to long will cause movement unsharpness due to breathing

- exposure not demonstrate abdominal anatomy and pathology

Post-processing evaluation of EI: The EI on the final processed image must be checked to verify that the exposure factors used were in the correct range to ensure optimal quality with the least radiation to the patient.

Appendix P: Government Hospital Permission Letter

Province of the
EASTERN CAPE
HEALTH

EAST LONDON HOSPITAL COMPLEX
Frere Hospital, Amalinda, Private Bag/Ingxowa Eyodwa X 9047, East London, 5200
South Africa • Tel: (043) 709 2135 • Fax: (043) 709 2443 • Website: www.ecdoh.gov.za

INTERNAL MEMORANDUM

To:	Mrs. C. Nel, Student, NMMU, Faculty of Health & Environmental Sciences
From:	Dr. J. Thomas; Director Clinical Governance, Frere Hospital
CC:	Mrs. J. Scholl; Acting Hospital Manager & Clinical Support Services, Frere Hospital Mrs. C. Gratz; Assistant Director Radiography, Frere Hospital
Subject:	Research Request: Radiographic image recording techniques when using computed radiography imaging systems in the Eastern Cape Province.
Date:	02 October 2015

Your correspondence for the above Research Request refers. Your request to access Frere Hospital has been approved.

It is requested that a copy of the completed analysis be submitted to this office for record purposes.

You can liaise with the following persons to coordinate the research:

1. Mrs J. Scholl, Tel: (043) 709 2654
2. Mrs C. Gratz, Tel: (043) 709 2210

Regards,

Dr J. Thomas
Clinical Governance Director: Frere Hospital

United in achieving quality health care for all

24 hour call centre: 0800 0323 64
Website: www.ecdoh.gov.za

PGDP EASTERN CAPE 2004 - 2014
Ikamva eliqaqambileyo!

Appendix Q: Private Hospital Permission Letter

EAST COAST RADIOLOGY

VAT REG 4020105641
PR3803414

DR.M.P. TARBOTON, DR. A.J. HORSELL, DR. A.W. RUSHTON, DR. W.J.S. STRYDOM, DR. H.S. WILLIAMS-JONES, DR. A CHACKO

P.O. BOX 7460, EAST LONDON, 5200 PH: 043- 7222453 FAX: 043- 7432063
EMAIL: practicemanager@eastcoastradiology.co.za

6 October 2015

Dear Members of the CUT Ethical Committee

RE: Request for permission to conduct a research study: IMAGE RECORDING TECHNIQUES WHEN USING COMPUTED RADIOGRAPHY IN THE EASTERN CAPE PROVINCE

We have considered and evaluated the request submitted by Mrs C. Nel for permission to conduct the proposed research study. Consideration has been given to the ethical implications of this research study based on her written requisition to the department.

We acknowledge to not having any objections, ethical or otherwise, to this research study and hereby provide permission for Mrs Nel to conduct her study at our institution.

Yours faithfully

Hendrik Cronje
Practice Manager

Appendix R: Statistical Biostatistician

Maryn Viljoen
Statistics Consulting Services

maryn.viljoen@vodamail.co.za
082 823 5731

Protocol and research methodology consultation • Ethical consultation • Database construction and capturing of data
Analyzing data using statistical software packages (SAS Version 9.1.3) • Statistics consultation services to analyze and interpret data
Conveys results with statistical tables and figures where needed

Attention: Ethics Committee Chairperson
Block D, Room 115
Francois Retief Building
Faculty of Health Sciences
University of the Free State

15 September 2015

Title: "RADIOGRAPHIC IMAGE RECORDING TECHNIQUES WHEN USING COMPUTED RADIOGRAPHY IMAGING SYSTEMS IN THE EASTERN CAPE PROVINCE."

Researcher: Mrs. C. Nel (Student number: 215144235)
M. Tech Radiography (Diagnostic)
Department of Clinical Sciences: Programme Radiography
Faculty of Health and Environmental Sciences
Central University of Technology (Free State)

I have seen and read through this protocol. I gave input and recommendations and will be the biostatistician responsible for the analysis of the data.

Maryn Viljoen
M.Sc. Risk Analysis (UFS)
maryn.viljoen@vodamail.co.za
082 82 35 731